THE APPLICATION OF THE NETWORK ANALYSIS SYSTEM IN OPERATIONAL PLANNING BY THE FIELD ARMY ENGINEER...A DOCTRINE

An abstract for a thesis presented to the Faculty of the U. S. Army Command and General Staff College in partial fulfillment of the requirements of the degree

MASTER OF MILITARY ART AND SCIENCE

by
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The opinions and conclusions expressed herein are those of the individual student author and do not necessarily represent the views of either the United States Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

Commanders and staffs must engage in active and continuous planning in order to make the most efficient use of available men, materiel, and facilities. The application of the network analysis system is one way to plan for the effective employment of resources. This management tool is widely used in both industry and in military engineer peacetime operations. However, Army theater of operations management doctrine does not expound upon the use of the networking technique.

The objective of this thesis is to develop a doctrine for the use of the network analysis system in operational planning by the field army engineer. Research is confined primarily to the examination of planning in a limited or general war. A procedure is developed for the army engineer to match his engineer resources with operational requirements and use the networking technique to produce a plan that effectively outlines and schedules an operation.

In the past eight years the military and civilian industry have developed network modeling as a new approach to planning, scheduling, and controlling a project. Two pioneer approaches, themselves quite similar, are the basis for most network technique variations--the Program Evaluation and Review Technique (PERT), and the Critical Path Method (CPM). Both concepts use the network modeling technique with certain unique principles. The network analysis system is the name given to network modeling by the U. S. Army Corps of Engineers. This technique prescribes a method of graphically portraying conventional planning, and permits the application of both PERT and CPM theory in detailed planning.

The network analysis system consists of three basic aspects; which are:

(1) The development of a model (also called a diagram) of the proposed plan of work. The model consists of interconnected arrows and circles. Arrows represent the tasks which must be accomplished in order to complete a project. Circles represent events in time. The model results from a logical analysis of the mission to be accomplished. A planner starts with a general concept and develops a sequenced group of required tasks, each placed in a pattern to show its relationship with the others.

(2) The evaluation and adjustment of the model to sequence the tasks in a way that will provide some positive assurance of reaching the desired objective within the limits of available resources.

(3) The use of the model to schedule and control the operation it represents.

The U. S. Army Corps of Engineers has demonstrated that the network analysis system is a very useful tool for planning and scheduling contract construction. Also, in a very limited way, at least, both Seventh and Eighth Army engineers are using the technique to aid in planning engineering tasks.

As both a brigade commander and the staff engineer, the field army engineer continuously engages in operational planning. Army doctrine prescribes a general sequence of six phases to guide the engineer in planning. The methodology closely parallels the procedure for engineer operational planning which is outlined in several field manuals.

Doctrinally, the Army sequence of planning fails to provide detailed guidance to assist a planner in developing a method for planning project execution. A gap in doctrine seems to exist between the procedure established for deciding upon a course of action and the next step where complete plans are prepared. In general, field manuals identify major tasks to be accomplished on common engineer projects; however, the job of integrating these tasks into a construction sequence and schedule is left up to the planner.

A doctrine is proferred in the thesis which applies the network analysis system to expand that part of planning theory which deals with the task of visualizing how a project will be completed. The system provides a means for developing a mission statement into a sequence and outline schedule of a planned operation. The proposed doctrine prescribes that a graphical model will be constructed to represent the sequence in which a project is to be executed. The model is also redrawn by orienting it to a horizontal time-scale and adjusting task starting times so as to provide either the least costly, in terms of resources, or the least time consuming plan. A unit-loading diagram is appended to the model to aid in project analysis.

The proposed doctrine integrates the network modeling technique with the six-step sequence for Army long-range planning. It can be a useful tool to the army engineer when he plans combat service support operations. In this regard, network modeling may be of limited value in his planning if unit resources are absolutely fixed. However, this limitation is minimized through the careful scrutiny of all sources of labor.

The proposed doctrine can also be a useful tool in planning the engineer combat support for a major field army tactical operation. With minor modification, the doctrine has convincing application when used to plan major engineer projects such as a deliberate river-crossing operation.

The doctrine does not propose to stand alone as an all-encompassing planning tool. Rather, it is meant to help the army engineer in drawing in all the diverse aspects of his total planning effort. It helps him to maintain a good perspective of the total engineer requirement.

It is recommended that the proposed non-computerized application of the network analysis system be tested in the field. Testing will likely stimulate increased interest in this planning tool and subsequently lead to appropriately revised Army planning doctrine.

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PREFACE

The Department of Defense Programming System places significant emphasis upon obtaining the greatest return for the "defense dollar" in programming and employing men, materiel, and facilities. Commanders and staffs are expected to engage in active and continuous participation in the programming process. The use of the network analysis system is one way to plan for the efficient use of resources. This management tool is widely used in both industry and in military peacetime operations. However, details for its use have not been integrated into Army manuals which prescribe management doctrine for the theater of operations.

The purpose of this paper is to formulate a doctrine for the use of the network analysis system in operational planning by the field army engineer.

The scope of the research is confined primarily to the examination of planning conducted by the army engineer in a limited or general war. A procedure will be developed for the army engineer to match his engineer resources with operational requirements and use network modeling to produce a plan that effectively outlines and schedules an operation. The paper expounds upon the problems and intricacies of planning. It purposely omits a broad discussion of the use of network modeling in controlling project execution. A thorough analysis of the function of project control is beyond the scope of this paper. In addition, the network analysis system is analyzed in terms of its basic non-computerized concept. The author acknowledges that the technique has wide computerized application; however, such use is presently too sophisticated for the field army engineer's use in a theater of operations.

The majority of source material is located in the holdings of the U. S. Army Command and General Staff College Library Archives. Technical material pertaining to network modeling systems is located in the general stacks of the library and in files retained by the Department of Command.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

For many years now the military has strived to improve the quality of its managerial capability at unit level. Service school curricula continue to stress the need for developing leaders who are well grounded in their ability to solve problems and make sound decisions. For the most part, the training programs are successful. In the 1965 Army the military manager consistently demonstrates his ability to organize for work and effectively accomplish an assigned mission.

The manager directs mission execution through the organization he establishes to do the work. His control techniques will vary depending upon the nature of the work.

Special techniques are used to aid the manager in each step of the management sequence. At unit level the commander and his staff habitually use a variety of management tools in their work. The following examples list some well known tools that are used to organize resources for work:

(1) The commander's format for the estimate of the situation, which aids him in reaching sound and timely decisions.

(2) The operation officer's standard five-paragraph operations order.

(3) The intelligence officer's format for recording his collection plan.

(4) The logistician's charts of major items of controlled equipment.

(5) The maintenance officer's records of equipment status.

In some way each tool aids the commander or his staff in gathering facts, analyzing the situation, deciding what to do, and planning the most effective use of available resources.

Some managers are more religious than others in their use of planning tools. The fact remains that most planners develop some system or technique to help simplify their jobs.

Often planners are troubled with the thought that perhaps an important fact will be overlooked. On the other hand, the problem of too much information may also cause some concern. Planners can be overwhelmed with bits of information, problem areas, and a maze of subtasks that need to be accomplished. The job of deciding what to do is often easy, but deciding how to do it can be most difficult. If a planner becomes too discouraged he may choose not to plan the job, but rather to "play-it-by-ear."

The problem of voluminous data faced the planners of the Polaris Fleet Ballistic Missile System in 1957.[1] The Navy assigned the planning function to its Special Projects Office with instructions to use all haste in the economic, efficient, and timely development of the Polaris. By 1958 a statistical technique was developed to aid in planning and controlling the project. The technique was called PERT-Program Evaluation and Review Technique.[2]

The fundamental concept of PERT involves the use of a graphical model, or network, to portray a program plan. The technique portrays

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[1]U. S., Department of the Navy, Special Projects Office, POLARIS Management, Fleet Ballistic Missile Program (Washington: U. S. Government Printing Office, February 1961), p. 2.

[2]Ibid., p. 12.

subtasks of a project in relation to recognizable points in time at which the subtasks begin or end. The network provides a convenient graphical description of the interactions and interdependencies of the subtasks. In the Polaris program the PERT concept provided decision information whereby management applied its resources to best accomplish the development and production of the weapon system.

In the six years that followed the development of PERT approximately fifty extensions evolved from the basic theory. Various agencies of the U. S. Government as well as industry have developed acronyms of PERT. Each applies the same basic technique--network modeling.[3]

One variation of the network modeling technique is called CPM--Critical Path Method. CPM has received wide utilization on construction projects. In 1963 it became the policy of the Army Chief of Engineers to encourage the use of the networking technique in contract construction.[4] Today the system is used extensively in projects sponsored by the Corps of Engineers.

The applications of network modeling are far reaching. There is no reason to doubt that the technique may have some application in the theater of operations. Military field commanders are continuously engaged in planning. The problem of integrating available resources to accomplish an assigned mission requires the close attention of all leaders. Consequently, staff officers are habitually engaged in planning for future operations.

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[3]C. W. Borklund, "Is PERT All that Good?," Armed Forces Management, January 1963, p. 11.

[4]U. S., Department of the Army, Office, Chief of Engineers, "Administration, Network Analysis System," Regulation 1-1-11, 15 March 1963, p. 1.

The field army engineer, as both a brigade commander and a special staff officer, is vitally concerned with operational planning. It may follow then that the general technique of network modeling has some application in his wartime planning mission. This paper reflects the research that has been done in an attempt to cultivate this theory. In succeeding chapters these points will be developed:

(1) The network analysis system, non-computerized, is an effective planning tool that can be used in the field.

(2) In the theater of operations, the field army engineer engages in extensive long-range planning.

(3) The army engineer is guided by an Army accepted sequence for planning.

(4) Military planning doctrine is weak with respect to the procedure that is established for transposing a decision of what has to be done into a procedure and scheduled plan of how the work will be accomplished.

(5) The field army engineer can improve his techniques for operational planning by using the concept of network modeling.

Chapter I introduces the network analysis system and elucidates its ability to help plan for the employment of resources in project execution.

Chapter II offers some examples of recent military applications of the network analysis system.

Chapter III delves into the functions of the field army engineer and highlights his most active roles in World War II and in the Korean War.

Chapter IV analyzes the engineer's planning function. Operational planning is discussed as an extension of the general sequence of Army planning.

A methodology is proposed for phasing the field army engineer's sequence of operational planning.

A doctrine is developed in Chapter V to outline the use of the network analysis system in operational planning by the field army engineer. The proposed theory integrates the networking technique with the general sequence of Army planning, as interpreted in Chapter IV. A hypothetical planning problem is presented to clarify the doctrine.

The doctrine is tested in Chapter VI by using the record of the Ninth U. S. Army's crossing of the Rhine River in World War II as a situation vehicle.

The paper concludes with a critical reanalysis of the proposed doctrine.

CHAPTER I

THE NETWORK ANALYSIS SYSTEM

General Concept

A new technique.--Planning and organizing for work is a never-ending management responsibility. In the past several decades many techniques have been developed to help ease the task of organizing for work. In recent years the function of planning has been aided tremendously by the invention of a new technique commonly called networking. The technique is being rapidly developed and is called by many names. The above chapter title represents the name given to networking by the U. S. Army Corps of Engineers.[1]

Today networking is widely accepted by industrial, scientific, and governmental organizations as a valuable tool for planning work.

This chapter introduces the networking concept and expounds on two of its pioneer approaches--the Program Evaluation and Review Technique (PERT), and the Critical Path Method (CPM). Both approaches use the basic network modeling technique, with certain unique principles that will be developed later in this chapter, as a basis for planning, scheduling, and controlling work.

Definitions.--The network analysis system is a method of graphically portraying conventional planning. It is an orderly way of planning, and

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[1]U. S., Department of the Army, Office of the Chief of Engineers, "Administration, Network Analysis System," Regulation No. 1-1-11, 15 March 1963, p. 1.

generally compliments the military approaches to problem solving, the estimate of the situation, the staff study, and the general sequence of planning. The system is a way to translate a broad concept of operations into a detailed and integrated plan of action. It is a management tool which emphasizes the processes of coordinated action, schedules, and control. It forces a manager to deal with the critical problem areas before beginning actual work.[2]

The system consists of three basic aspects; which are:

(1) The development of a model (also called a diagram) of the proposed plan of work.

(2) The evaluation and adjustment of the diagram to provide a degree of assurance that, if the plan is followed, there will be a minimum risk in reaching the desired objective within the prescribed limits of available resources.

(3) The use of the model to control the operation it represents.[3]

A network model is a two-dimensional plan of the steps and sequences to be followed in achieving the desired objective or goal. The network model consists of three components--events, activities, and relationships.[4]

An event is a specified accomplishment in a plan. It is a milestone--a clearly identifiable point in time to mark the start or completion of a specific task. An event may be a point at which something is physically

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[2]Gabriel N. Stilian, et al, PERT, A New Management Planning and Control Technique (New York: American Management Association, Inc., 1962), p. 149.

[3]Ibid., p. 37.

[4]Booz, Allen and Hamilton, Inc., The Management Implications of PERT (New York: Booz, Allen and Hamilton, Inc., 1962), p. 5.

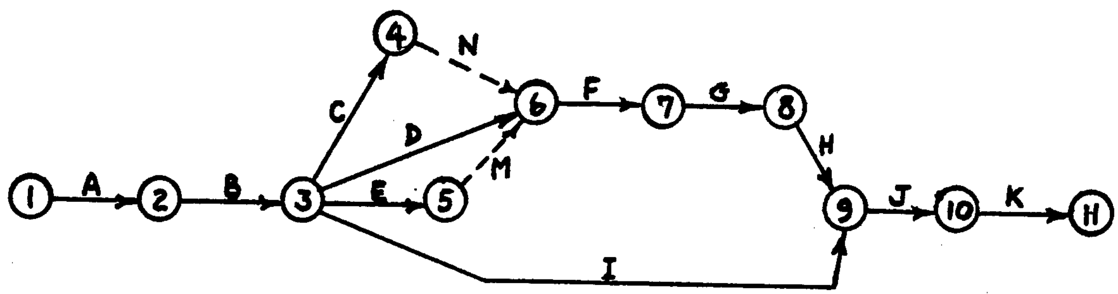
accomplished, or where a decision must be made. There may be work leading to an event, but the event itself requires no time, and therefore it represents no allocation of resources. The key objective or goal of an operation can be achieved only after all of the project events have been reached. An event is usually represented on a network by a circle.

An activity is the clearly definable work required between two events; it is limited by them. It represents a task to which a particular quantity of resource will be applied. The sum of all the project tasks accomplished on a job represents the total expenditure of resources to achieve the key objective. Proper identification of all the necessary tasks is probably the most important aspect of the network analysis system. Activities are represented on the network by arrows.

Relationships are the sum total of the affiliations, connections, and dependencies of the activities upon one another. Planners identify these relationships as they proceed through the function of visualizing the conduct of work from start to finish. For example, the first task on a job, by definition, is related to all other tasks in that it must be started at the beginning of the project. The remaining tasks follow in some orderly sequence of execution.

Developing the network.--Placed in proper sequences and combinations the activities and events are shown in a network model to depict the relationships between all the tasks involved. Figure 1 shows an example of a network model that could be drawn to represent a plan for demolishing a building. The model depicted illustrates the basic concept of modeling which is common to most network analysis techniques, including PERT and CPM.

NETWORK MODEL:



EXPLANATION:

Preceding Event	Following Event	Activity Description	Activity Letter
1	2	Plan demolition	A
2	3	Set up plant	B
3	4	Remove roof	C
3	6	Remove interior partitions	D
3	5	Remove exterior siding	E
4	6	Dummy (no work)	N
5	6	Dummy (no work)	M
6	7	Remove main walls	F
7	8	Remove flooring and plumbing	G
8	9	Remove foundation	H
3	9	Clean up and remove debris	I
9	10	Back fill and grade	J
10	11	Clear site	K

Fig. 1.--Network Model for the demolition of a single story (hypothetical) building.

A network model is developed from a logical analysis of the mission to be accomplished. A planner forms a graphical presentation for project execution by starting with the general concept and developing specific tasks to be completed.

There are seven steps in network construction; they are as follows:

(1) Define the prime objective--that mission toward which all planning is to be directed.

(2) Identify supporting objectives--a groupment of the major tasks to be completed in order to attain the prime objective.

(3) Identify work packages--work packages are the skills or specialties of the work force that are required to achieve the supporting objective. In Figure 1 the skills required to demolish the building include earthwork, plumbing, carpentry, and general labor. Work packages are a convenient subdivision of work for cost accounting purposes. Each may contain from one to several detailed tasks (activities) to be completed.

(4) Select the detailed tasks to be accomplished.

(5) Select the events to be achieved--events define the accomplishments in the project.

(6) Sequence the activities and events--determine the order of execution of each activity. Also, establish the relationships of activities to events.

(7) Layout the network model in the manner depicted by Figure 1.

The network model identifies each activity and places it in a pattern to show its relationship with each of the others. Both series and parallel sequences of activities will occur in reaching the key objective.

A set of rules has evolved during the development of the technique of network modeling. Compiled in Appendix A is a collection of the currently accepted mechanics of network construction. For the most part, these rules have been adopted by both governmental and civilian agencies, and are used with numerous techniques such as PERT and CPM.

The basic model shown in Figure 1 is by no means the end product of network modeling. The next step in the technique is to visualize the amount of resources, in terms of work force and materiel, that are required to complete each activity. These requirements are either listed on the network or appended to the accompanying table of explanation.

Following the application of resources, the next step in developing a comprehensive model is to secure time estimates and calculate the expected time for each activity.[5] These times are applied to the network model; they materially assist planners to clearly visualize the concept of execution.

A time length is calculated for each series-sequence of activities which connects the starting with the end event. In Figure 1 four series-sequences exist in the model. Each represents a specific time length of activity. The longest time length is called the critical path. This path sets the time required to accomplish the project.

If costs are to be analyzed, the final step in preparing the model is to calculate both direct and proportionate indirect costs related to each activity. The cost of each activity is applied to the network and the diagram is complete.

Evaluation of the network.--The completed network contains a wealth

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[5]The PERT-Time method for calculating expected times is discussed in the next section of this chapter and in Appendix B.

of significant data. It provides several important facts and relationships to the planner; they are:

"(1) The expected project duration.

"(2) The tasks that are critical.

"(3) The points in time relationships when tasks can begin and finish.

"(4) The time points at which they [tasks] must begin and finish so as not to interfere with the overall duration of the project.

"(5) The tasks that must be expedited if it is desired to reduce the project duration.

"(6) The leeway available for scheduling individual tasks."[6]

Analysis of a network is a form of management by exception. The manager can study the network and determine those critical tasks which require his close supervision. For example, when time is a critical resource, it may become evident that only a small number of the total tasks actually control the time required to reach the key objective. Then, he would see that a delay of one or more of these tasks delays the entire project. The manager manipulates all of his resources to most effectively reduce the total requirement for manpower, materiel, and time. In any one situation one of these three broad categories could be held as the critical element in planning. However, on most industrial projects costs are the overriding limiting factor in planning. In this instance the manager orients his thinking to concentrate on maximizing profits by minimizing project costs. A military manager, particularly in the theater of operations, may hold that dollor costs are not significant in expressing project effectiveness. Consequently, the military planner may declare time,

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[6]U. S., Army, The Engineer School, "Student Notes, Network Analysis Systems," Fort Belvoir, 1963, p. 6.

manpower or even materiel to be the controlling factor in his planning.

A completed network normally represents one concept for completing a project. However, this does not imply that in network modeling only one course of action is ever analyzed. On the contrary, if time permits, and other feasible courses of action are apparent, a planner may prepare a completed network for each of two or more distinguishable methods for accomplishing a job. In this case the manager will carefully analyze the advantages and disadvantages of each plan before deciding upon the scheme of action.

Applications of the network modeling technique.--Network modeling is a technique that can be incorporated into a general military sequence of planning. One or more outline networks, that give broad concepts for project execution, may be prepared to support each course of action to be analyzed during preliminary planning. When the commander chooses a course of action the corresponding network model can be issued with operation plans so that subordinates can complete their detailed planning.

The network technique supports a subdivision of the planning requirement. Each level in the organization can proceed independently with its planning function. Subordinates may be required to complete networks to represent plans for accomplishing assigned activities. Then, any number of sub-networks can be put together, with a master network as an index, as it were, to form a comprehensive plan.

Top management will make those network adjustments that are required to provide a complete plan for a harmonious execution effort.

The concept of network modeling enhances planning for a time phased project execution. A completed network model will not in itself include a time scale. Note in Figure 1 that neither the length of activity arrows nor the positions of the events were related to time. This is done purposely in the initial stages of networking to avoid introducing a bias into the estimates of resource and time requirements.

Scheduling can be greatly simplified by refining and orienting a network model to a horizontal time scale. Then each network event becomes a milestone in actual time. That is, each activity will be scheduled to start and be completed at a specific point in time. A horizontal time scale incorporates non-work days, if they are planned.

A bar-graph, such as shown in Figure 2, is a logical extension of a time-oriented network model. It can be used to regroup activities into work packages of similar skills, that are oriented to the vertical axis. The entire scheduling function is quite reduced in magnitude when a network model is developed during the planning phase. If sound judgment were used in the preparation of time estimates then little guesswork will be required to complete a schedule.[7] [8]

Network modeling can be a valuable tool not only in planning and scheduling a project but also in costing a proposed operation. Most project managers operate with definitely limited resources. Except in a theater of operations, even military managers may be expected to cost their projects.

Costing the separate activities in a network can be a time consuming job; at times the task may be virtually impossible. However, particularly

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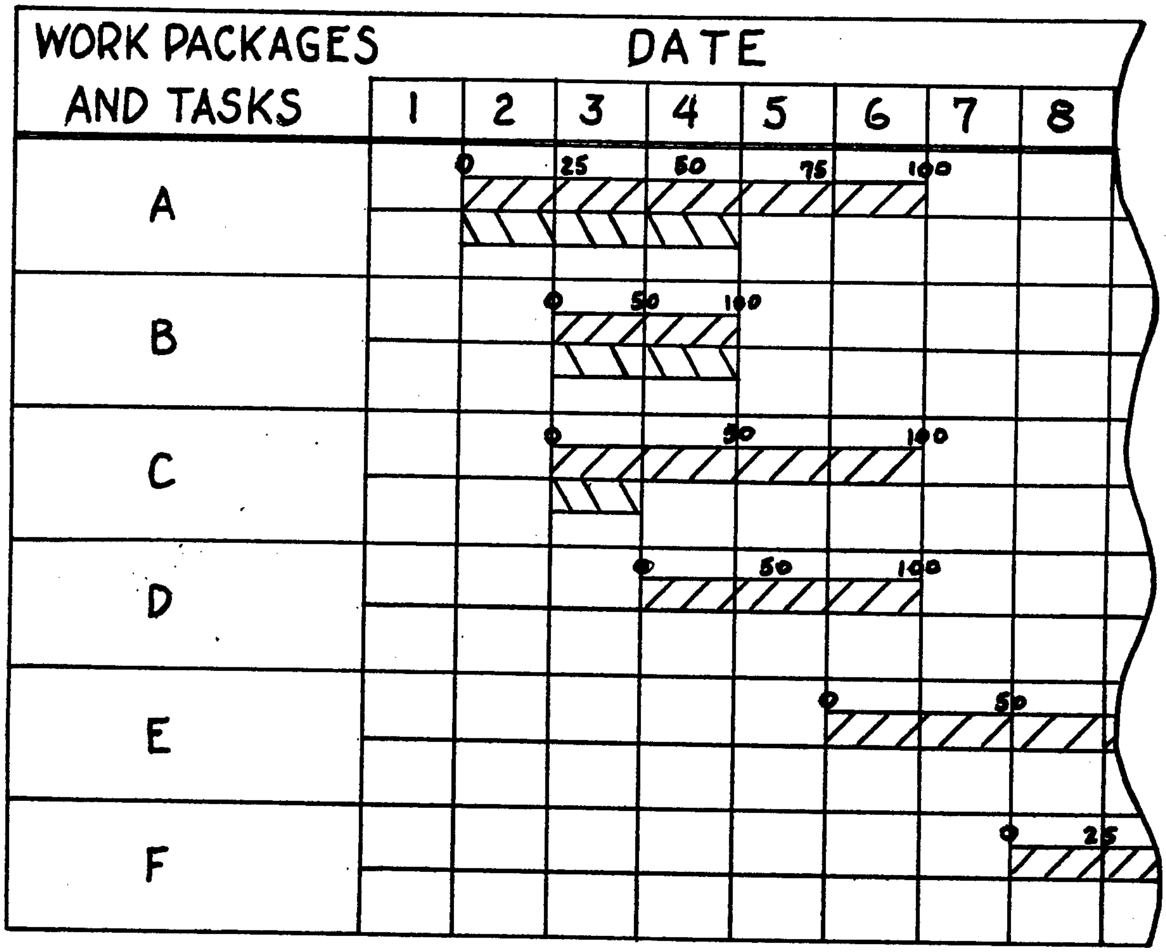
[7]Note that in the network analysis system the functions of planning and scheduling are distinctly separated. As stated above, a network diagram does not include a time scale. When drawing the initial sketch, a planner concentrates on producing a picture of the most workable sequence of activities. He attempts to reveal each interdependency that exists between the tasks.

[8]Stilian, op. cit., p. 41.



Scheduled progress

Actual progress

Note: This sample bar-graph is not related to Figure 1.

Fig. 2.--Sample Construction Operations Schedule and Progress Chart (bar-graph).

in industry, all resources are reduced to a monetary value as the common denominator for overall project control. The resources applied to each activity need to be identified in absolute detail. For example, manpower requirements must be stated both quantitatively and qualitatively. Also, material requirements must be expressed in complete bills of material. And, equipment requirements need to identify every conceivable piece that will be used and delineate time requirements. Indirect costs cannot be overlooked, particularly when more than one course of action is being analyzed during project planning. The estimated total cost of a proposed project may be used as a management aid in evaluating a method of execution or simply as a device to insure that a plan stays within some imposed cost ceiling.

A network model serves as a convenient communications medium during the entire project, from inception through completion.[9] In early planning conferences the first network sketch provides an outline for discussion. It can portray the broad concept of the operation in a much simpler way than the same facts prepared in narrative form. When firm plans are developed the network provides continuity and a basic planning tool for common reference. Color coding can be used to enhance cross-references to sub-networks and schedules. The model can help to answer many questions which will arise during execution. In addition, the model can be a valuable tool for briefing visitors and new arrivals in the organization.

However, one of the most important applications of the network analysis system is to control an operation. Few complex and time consuming projects

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[9] Ibid., p. 38.

move along exactly as scheduled. Many factors and unpredictable difficulties may necessitate changes in plans. The network is a useful tool for planning the trade-off of resources during project execution. If a timely reporting system is used, the network can be updated periodically and will reflect trends as they develop and forecast their impact on subsequent tasks. Looking ahead on the network, the manager can identify surplus resources and apply some of them in critical areas. In each instance where a trade-off appears necessary, its effect can be carefully analyzed and compared with other possible changes. In this way management hopefully arrives at the optimum adjustment of resources.[10]

Detailed control techniques, including a variety of periodic reports, can be used to help keep a project on schedule and within monetary limits. The PERT system for reporting actual work performance is discussed in the next section of this chapter. PERT suggests a wide variety of useful project feedback reports. Further discussion of reports is omitted at this point.

While the concept of project control is stressed by most network technique variations, each approach to detailed control varys slightly.[11] The military, independent management consultants, and industry have independently developed a large family of specific systems. In the following sections two widely used concepts are analyzed. The first to be discussed is called the Program Evaluation and Review Technique. The second is called the Critical Path Method. Each is a valuable system for planning, scheduling, and controlling an operation; and, each has distinct advantages and limitations.

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[10]Booz, Allen and Hamilton, op. cit., p. 15.

[11]Ibid., p. 4.

PERT - Program Evaluation and Review Technique

"PERT is a set of principles, methods and techniques for effective planning of objective-oriented work, thereby establishing a sound basis for effective scheduling, costing, controlling and replanning in the management of programs."[12]

Background.--PERT was developed and first applied in 1958 in the U. S. Navy's Polaris Fleet Ballistic Missile Program. Under the auspices of the Navy's Special Projects Office, naval planners worked with Booz, Allen and Hamilton, Incorporated, the Lockheed Aviation Corporation, and others to develop the technique.[13] [14]

PERT was partially evolutionary. The concept of graphical analysis of interrelated activities has long been used in electrical engineering, fluid mechanics, and computer programming flow charts. Also, PERT drew ideas from the concept of project scheduling with a bar-graph. In addition, it applied the technique of milestone reporting; that is, the system of identifying and reporting the status of critical points in a project, such as the start or completion of key tasks.

The developers of PERT merged the evolutionary management systems with their own ideas for time and cost estimates, a critical path of work activity, and a new type progress-reporting system. The result was PERT--an improved approach to planning and control.

The PERT Network.--The PERT network flow chart concept germinated the seeds of thought for the broad development of the network analysis

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[12]U. S., Government, PERT Coordinating Group, PERT Guide for Management Use (Washington: U. S. Government Printing Office, June 1963), p. 22.

[13]Booz, Allen and Hamilton, op. cit., p. 4.

[14]U. S., Department of the Navy, Special Projects Office, POLARIS Management (Washington: U. S. Government Printing Office, February 1961), p. 4.

system. The basic concept of network analysis discussed in the preceding section of this chapter is synonymous with the PERT approach. Though it was a pioneer approach, PERT has benefited considerably from the research and effort that American industrial management recently expended in this area. Today, networks are developed with a universal language and under common rules of logic. These concepts are summarized in Appendix A.

The PERT time concept.--When the basic network model is established PERT introduces the element of time based upon several variables; the two most important are the planned use of resources (manpower, equipment, and materials), and the average resource application rates (e.g., the length of the work week and the number of shifts).[15]

PERT urges that time estimates should be made by personnel who are most intimately related with each type of activity. It accepts the fact that the quality of time estimates is dependent upon the experience and understanding of each participating individual.

Either a single time estimate or a range of estimates is made for each activity. If a range of estimates is considered necessary by planners, usually three are made--the optimistic, the most likely, and the pessimistic. The range infers that a degree of uncertainty exists. This groupment of times is used to calculate a statistically expected time for each activity. Appendix B describes the general theory for this calculation.

The time estimate obtained for each activity is applied to the network model. Each time-path in the network is analyzed and the total path time-length is computed. That path which requires the maximum expenditure of time is identified as the critical path. The expected project

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[15]U. S., Government, PERT Coordinating Group, op. cit., p. 22.

completion time is estimated using the time length of this longest path.

Having prepared an estimate for the project completion time the planner works backward along each path in the network to establish the latest allowable completion time (T_L) for each activity. Then working forward along each path from the start of the project an earliest expected completion time (T_E) is calculated. The values of T_E and T_L are tabulated for each event and slack time is calculated. Slack is the difference between the latest allowable completion time and the earliest expected completion time.

Slack exists in each time path of the network except on the critical path. Consequently, some idle resource is represented on each of the other paths of the network.

The earliest expected project completion date is compared with any prescribed date. If the desired completion date is earlier than the expected date, management may decide to take any of the following courses of action:

"(1) Modify the network by introducing greater concurrency of effort.

"(2) Load [reserve] resources on limiting activities.

"(3) Change the scope of activities.

"(4) Change the performance requirements.

"(5) Balance the plan by reallocating resources among activities."[16]

PERT provides an approximate method for determining the probability of meeting a scheduled activity or project completion time. The identification of an optimistic and a pessimistic time estimate must be made for

[16] Ibid., p. 24.

each activity. Appendix B develops the theory for this system of probability calculations. The more sophisticated, and often computerized, PERT systems do calculate the probability of meeting selected milestones in the network.

In summary, the PERT Time concept shows all the work that must be done, identifies required resources, estimates activity and project completion times, reflects various interdependencies, and measures the relative uncertainty of accomplishing the events in the plan, as scheduled.

The PERT Cost concept.--The PERT Cost technique complements the PERT Time concept and aims to determine where cost overruns may and do occur in a project. It provides the mechanics for relating costs to schedules and budgets.

The application of PERT Cost starts during the development of the network model. The work packages, which are identified early in the planning, provide a logical subdivision of work for cost accounting purposes. Normally, a work package is the lowest level of identification of costs to the work performed.

Each work package is normally supervised by one person in the task organization. Hence work packages are a convenient way to start building a task organization.

PERT stresses the importance of preparing detailed cost estimates for work to be done. Supervisors in the proposed organization who will subsequently be responsible for completing each work package prepare the cost estimates.

Management uses the cost calculations as a tool for analyzing proposed schedules and planned resource application. They aim to eliminate all unnecessary manpower costs and premium payments for materials and services.[17] The preliminary cost estimates prepare the groundwork for the PERT system for reporting actual performance.

The PERT Cost reporting system.--It is a matter of judgment as to how much detailed reporting management will require under the PERT system. In general, periodic summary calculations are made to compare previous estimates with the actual costs incurred for each work package. Calculations are made to compare estimates with the actual costs incurred for each work package. Calculations are also made to predict any future cost overruns. Activities that are located on the PERT Time network critical path will receive particular attention. The PERT Cost system attempts to highlight difficulties in performing work early enough for management to take corrective action.[18]

The PERT Cost reporting system is comprised of several detailed reports, which, as a group, provide management with necessary decision information. Reports of particular significance include the following:

(1) Management Summary report.--This report presents an overall time and cost schedule for the project as a whole, and for each work package. It provides management with a forecast of the cost overrun or underrun to date by comparing planned versus actual costs. The report provides a latest revised estimate for total costs required to complete the project and each work package. The Management Summary Report also compares the scheduled milestone and project completion dates with the latest revised estimates for each occurrence. It gives management a concise picture of the project status and identifies those problem areas that require management's attention.

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[17] *Ibid.*, p. 40. [18] *Ibid.*

(2) Cost of Work Report.--This report is a graph of both actual and budgeted costs versus time. It shows management a graph of planned costs with a graph of actual costs to date. It lists the value of the work performed to date to show current underrun or overrun. In addition, it graphically projects costs to project completion and forecasts final underrun or overrun. Cumulative costs are oriented to the vertical axis and time is projected along the horizontal axis. The most significant aspect of this periodic report is that trends toward either overrun or underrun are presented on an easily read graph.

(3) Schedule Outlook Report.--In a graphic display, this report shows the periodic trend of the estimated project completion date in terms of weeks ahead or behind schedule. Time, generally in terms of weeks, is oriented to the vertical axis. The zero line for weeks ahead or behind schedule is drawn horizontally across the center of the page. At the end of each reporting period a point is plotted to represent the status of work, oriented to a calendar of weeks or months drawn along the horizontal axis.

(4) Cost Outlook Report.--This report is laid out on a graph similar to the format for the Schedule Outlook Report. It shows the periodic trend of the projected overrun or underrun. Overrun and underrun costs are drawn along the vertical axis from a zero overrun line which is centered horizontally on the graph. At the end of each reporting period a point is plotted on the graph to represent the current estimate of projected overrun or underrun costs projected to completion of the job.

The PERT Cost reporting system aims toward minimizing the cost of the operation. The frequency of the reports will depend on the length of the project and the particular desires of management; however, in actual practice many PERT users have employed a biweekly reporting system.

Summary.--PERT is a set of principles which aids a manager in the effective planning of object-oriented work. It establishes a management process cycle that starts with the establishment of detailed objectives. The objectives support the prime goal of management. Planners translate objectives into work packages and subsequently into a list of detailed activities that must be accomplished. These activities are highlighted through the use of milestones to magnify critical steps in the project.

PERT planners develop a network model to place each activity in a pattern and show its relationship with each of the others. The network is used to forecast project duration, tasks that are critical, and as an aid in project scheduling. In addition, the model can serve as a convenient communications medium during the entire project.

PERT provides for the development of a detailed cost control system to aid management in setting further objectives, evaluating progress and redirecting work effort when variance occurs. A series of cost reports provide necessary management decision information.

The Program Evaluation and Review Technique is widely used in industry. Applications have encompassed many field of human endeavor. On large projects, the system employs a digital computer to handle the wealth of data which is periodically gathered for management's review. However, noncomputerized applications of the PERT Time and PERT Cost techniques are both feasible and practicable. In more complicated applications management must be careful not to let PERT become the end rather than the means to improved management.

CPM - Critical Path Method

CPM is the term applied to a technique that was developed in industry and uses the network modeling theory to plan, schedule, and control a project. It employs mathematical formulae, statistical analysis, and either electronic data processing or manual computations as tools for project management.

Background.--CPM had its inception in 1957 on a project that the Remington Rand Division of the Sperry Rand Corporation accomplished for the E. I. du Pont de Nemours and Company.[19] CPM grew up in civilian industry at about the time that PERT was developed under U. S. Navy auspices. Today their basic approaches and techniques are quite similar. However, there is a basic characteristic which distinguishes CPM from the PERT Time concept. PERT stresses a trade-off of resources in the network model to reduce time and increase overall efficiency. CPM on the other hand identifies two general rates for applying resources to carry out a job--a normal rate and a crash rate.

The CPM normal rate is associated with the estimated total cost of the project (normal cost), if it is completed by a typical work force, in an average time for the work conditions present. This average time is also called the normal time.

The CPM crash rate is associated with the estimated total cost of the project (crash cost), if it is completed by an augmented work force, in the shortest possible time under the work conditions present. This

[19]Remington Rand Univac Corporation, Military Department, Fundamentals of Network Planning and Analysis (St. Paul: Remington Rand Univac, January 1962), p. 3.

shortest possible time is also called the crash time.[20]

Like PERT, the CPM system prescribes a timely reporting system to aid management in controlling resource application and in identifying problem areas. The reporting system is quite similar to the PERT reporting concept and will not be further discussed.

Time-cost assignment to minimize cost.--The CPM technique begins with the preparation of a basic network diagram. The modeling technique described in Appendix A is comparable to the CPM concept.

Once the network model is completed in draft form the planner applies resources of men, material and equipment to each activity. He strives to plan the execution of each task in the most efficient manner; that is, with the least total expenditure of cost. This application of resources is made at a rate consistent with normal operations. Hence, the time calculated to complete each activity is called the normal time of completion. The cost of the activity at this rate of application is called the normal cost. It is identified as the least expensive rate at which to complete the project.

Minimizing time.--Next, a set of calculations may be prepared to determine the cost of each activity if it is completed in the least possible time, called the crash time. Associated with this crash time is a crash cost, also calculated for each activity. The concept sounds simple; however, in actual practice the job is quite complex. An orderly summary of cost-time data is usually prepared to compare the crash rate for job performance with the normal rate.

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[20]Andrew Muir, "PERT? CPM? RAMPS?," Time and Motion Study, April 1963, p. 25.

The crash rate and the normal rate identify the gamut of a number of variable ways to do the job. If time permits, the planner may prepare several plans, each with a unique schedule, to show variations in starting and completion times for each activity and the related costs.

For a given tentative schedule one network path will be critical and each of the others will have some slack time. Each shorter time schedule generally will result in a higher cost estimate. Resources are applied to those activities that will experience the smallest change in cost per unit of time saved. Emphasis is given to the critical path of activities. A unique schedule can be identified each time that another path in the network becomes critical.

To aid the planner, CPM identifies three basic categories of slack as relates to each activity:[21]

(1) Total float, which is the slack time available when the preceding activities are completed at the earliest possible times and all the succeeding activities at the latest possible times.

(2) Free float, which is the slack time available when all the preceding activities are completed at the earliest possible times and all the succeeding activities are also completed at the earliest possible times.

(3) Independent float, which is the slack time available when all the preceding activities are completed at the latest possible times and all the succeeding activities are completed at the earliest possible times.[22]

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[21]CPM uses an additional term called float which is synomyous with the PERT term called slack.

[22]Stilian, op. cit., p. 152.

The planner continues to modify his planned method for accomplishing the job until he reaches a point where, in his own mind, it is not worth the additional expense to save further time. When he reaches this decision a final schedule is prepared for the proposed operation.

CPM is ideally suited for analysis by a computer program. On large projects involving fifty or more activities the required calculations will probably be too unwieldy for hand computations. Any time manual computations are required, because of the work involved, a planner will probably prepare a normalized schedule and one crashed schedule. In this instance activities along the initial critical path are compressed, along with any other activities which can be easily reduced in time at a nominal increase in cost. Manual analysis using CPM is limited only by the time and effort available to the planner; any number of schedules can be made if time is available.

Application of the Critical Path Method.--Table 1 shows a hypothetical example of the use of CPM to compare the cost-time relationships of various modifications of an original network model. Schedule A shows the anticipated cost for doing the job if it is done at a normal rate. Schedule D shows the costs that will be accrued if the plan is crashed to the most practicable limit in the mind of the planner. At this crashed rate idle resources are reduced considerably while the direct cost of the project rises to a projected maximum. Schedule D will cost $90,000 more than Schedule A, but saves management an estimated nineteen days in the length of the project.

Schedules B and C are variations of the normal rate. Each shows significant savings in time with a corresponding increase in cost. The top management of the proposed project must analyze the figures with the

TABLE 1

COST EFFECTIVENESS COMPARISON OF PLANS
(in thousands of dollars)

Rate Schedule	Normal A	Intermediate B	C	Crash D
Days required	61	56	51	42
Direct costs	$421	$442	$477	$529
Indirect and idle resource costs	$ 34	$ 27	$ 21	$ 16
Total Costs	$455	$469	$498	$545

corresponding networks and schedules and choose that course of action which best satisfies all contingencies.

Like PERT, choice of a plan of action is but the first of the two most significant applications of CPM. The control of project execution is enhanced considerably through a timely CPM reporting and updating procedure. The technique is comparable with the PERT Cost concept discussed earlier in this chapter. Management analyzes progress, identifies potential problem areas, and shifts resources as required to keep the project on schedule.

Summary.--The Critical Path Method is a network analysis system which, if properly used, will assist a manager in planning, scheduling, and controlling a project. CPM was developed in the American industrial environment as a tool for increasing job efficiency and reducing costs. It is a cost effectiveness technique which uses a network model to arrive at a sound course of action for accomplishing a work project.

The CPM concept employs the generally accepted technique of network modeling to aid in balancing known requirements with available resources. Through CPM, a planner can identify two distinct methods for completing a job--with the least reasonable cost and in a normal rate; or, in a minimum time, at a crashed, and correspondingly increased cost. These two methods bracket a variable number of unique methods for doing the work. Using either a computer program or manual computations, a planner can modify a normal method for job execution and save time through the judicious application of resources to the activities on a network model.

The Critical Path Method is widely used on construction projects where the interplay of costs and time often is a critical factor in making for profit or loss.

The CPM technique is an excellent tool for controlling a project. The common language and flow-chart type network model can be easily understood by all elements of the work force.

For military purposes, where an expression of dollar costs is generally insignificant in the theater of operations, the commander can use as his criterion, either manpower or materiel.[22] He may choose to reduce project completion time at a corresponding increase in materiel or manpower resource application.

Conclusion

Advantages of the network analysis system.--The network analysis system consists of drawing a picture of a plan of action in a form that is readily understandable throughout the organization. A series of calculations compliments this diagram to arrange time and resources together to form a schedule. Finally, control measures form that part of the system which permits management to analyze progress and act confidently to improve the productive effort.

[22]U. S., Army, The Engineer School, op. cit., p. 12.

The system has several good points; these include:

(1) Detailed planning is absolutely necessary; it cannot be avoided for it is an essential aspect of the system. The preparation of a network model requires a logical, accurate, and consistent approach to planning.

(2) The system clearly outlines the total number of tasks to be accomplished, and shows their interactions.

(3) Project milestones are established and sequenced to aid in work control.

(4) The network model gives management a good perspective of the overall plan.

(5) Problem areas are identified in time for management to react and keep the project on schedule.

(6) Subtask times are calculated early in the planning sequence and aid in detailed scheduling.

(7) The system provides an excellent tool for orienting and briefing personnel.

(8) Used in the execution of a lengthy project, the network analysis system forces management to up-date and examine the schedule in light of past performance.

(9) The project reporting system provides a wealth of data to assist in future planning of similar type projects.

Limitations of the network analysis system.--The network analysis system will never replace the manager. It will not think nor decide for the manager for it is simply a tool for effective planning and control. The basic technique has received wide publicity and many variations of the fundamental concept have been developed. Although there are numerous possible applications of the tool, management can easily become so entranced with the intricacies of the network analysis system that it becomes the end rather than the means to improved management.[23]

The following points must be weighed when considering the use of the system:

(1) The technique is probably not worth the effort on repetitive projects where standing operating procedures serve to control the operations.

(2) Inaccuracies may creep into the network because of limited experience and foresight on the part of the planner.[24]

(3) Time estimates may be unrealistic. The use of three time estimates in the PERT concept is significantly safer than a single estimate. However, as is the doctrine of PERT, the exclusion of random variables, such as acts of God and war damage, can make estimates unreliable.

(4) The accuracy of resource estimates will be affected by the planner's judgment and experience.

The network analysis system is well suited to general industrial management, construction project control, and research and development programming. The system is still under evolution. As management becomes more familiar with the technique we can expect significant extensions and a greater variety of uses.

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[23]Booz, Allen and Hamilton, op. cit., p. 5.

[24]Bruce Mikesall, "Uncertainties of PERT," Armed Forces Management, January 1963, p. 21.

CHAPTER II

EXAMPLES OF MILITARY APPLICATION OF THE NETWORK ANALYSIS SYSTEM

Introduction

The network analysis system has excellent potential for use in planning, scheduling, and controlling physical work. In general, it may possibly be a useful tool whenever a planner is confronted with an arbitrarily imposed deadline, a limitation on resources, or when the task to be accomplished involves many interrelated subtasks.

In March 1963 the Army Chief of Engineers reported that the network analysis system had already been used on more than eighty different Corps projects.[1] Some of the most significant projects reported were as follows:

"(1) Engineering planning for multi-purpose projects.

"(2) [Planning] "Operation Chlorine"--Salvage of chlorine bottles from a sunken barge on the Mississippi River.

"(3) [Preparation of] Hydraulic Studies.

"(4) [A] Plan and schedule for a series of ground-breaking ceremonies.

"(5) Preparation of reports for flood control.

"(6) Initiation of a new organization and program.

"(7) Mapping operations in Thailand.

"(8) [A] Plan and schedule [for] annual maintenance operations on hydro-electric generators."[2]

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[1]U. S., Department of the Army, Office of the Chief of Engineers, "Administration, Network Analysis System," Regulation No. 1-1-11, 15 March 1963. This regulation contains some excellent examples of the use of the networking technique, p. 10.

[2]*Ibid.*

These reports of successful uses of the network analysis system give a good indication of the system's versatility. Broader application may be possible. In fact, many of the projects listed above are similar in nature to tasks that would be accomplished in a theater of operations. For example, an army staff could use the technique in planning mapping operations, maintenance operations, manpower and reorganization studies, hydraulic studies, and large scale engineer construction projects; they too can use the technique.

The networking technique was recently used as a planning tool in the Eighth Army Engineer Section, Korea. The Chief, Intelligence and Mapping Branch used the Critical Path Method to plan a new route numbering system for Korean maps. In the form of a preliminary study, the plan outlined a program that will cover a four-year period when it is implemented. About 900 map sheets are to be modified. The army engineer staff will have to coordinate the efforts of ten separate agencies.[3] Although this appears to be a limited application of networking, at least a step has been made in the Eighth Army Engineer Section to apply the technique in planning.

Greater use of the network analysis system has been made by the Seventh Army Engineer in Europe. In 1963, Headquarters, Seventh Army, established a policy which publicized this planning technique. A letter of instructions to the Seventh Corps commander and the commanders of separate engineer groups directed that the Critical Path Method (CPM) would be used to plan, schedule, and control priority engineer work at the Seventh Army Training Center (Hohenfels and Grafenwoehr).

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[3]Capt. Paul Bazilwich, Jr., Chief, Mapping and Intelligence Branch, Operations Division, Office of the Engineer, Eighth Army, Personal letter to the thesis author, 3 Dec 64.

In 1964 each engineer battalion that trained at the Seventh Army Training Center planned at least one top priority project by CPM.[4] Networks that were completed in compliance with the instructions contained a comprehensive analysis of the proposed work. In general the networks provided a description of each key event, identified each activity, reflected a time estimate for each activity, identified the critical path, and showed where slack time was available in the network. Only one time estimate was prepared for each activity. The Seventh Army Engineer apparently felt that little value would be gained if planners used the PERT three-time concept or the CPM crash-time concept.

Seventh Army engineer battalions applied CPM in managing road maintenance, bridge and building construction, and range rehabilitation.[5] They were encouraged to train key personnel in the use of CPM and employ the networks as low as company level. At that level the networks were prepared in considerable detail by expanding upon outline-networks prepared at battalion level.

The outlook appears good in both Seventh and Eighth Armies for a wider use of CPM in planning, scheduling, and controlling engineer combat support operations.

Although relatively new in the area of military field engineering, the network analysis system has received wide acceptance in military contract construction activities. Encouragement by the Chief of Engineers has prompted the extensive use of the technique. Contracting officers now

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[4]U. S., Forces, Europe, Seventh Army, "Letter of Instructions, Engineer Construction Support, Seventh Army Training Center, CY 1964," Letter AETEN-OC, 4 December 1963, p. 3.

[5]*Ibid.*, Annex A.

require that contractors use the networking technique to manage many Corps financed military construction projects.[6]

Two examples of Corps of Engineer peacetime applications of the network analysis system are outlined below. In the first example the technique is used to plan the construction of a missile silo, as part of the Ballistic Missile Construction Program. The second example gives an indication of the versatility of the technique; this example demonstrates the use of the network analysis system to plan the annual inspection of a power plant. Even though they differ widely in scope, the two examples have at least one common characteristic--both projects consist of a number of interrelated activities.

Planning the Construction of a Missile Silo

In recent years, as the need for completed ICBM launching sites grew more urgent, the Chief of Engineers directed his field offices to work closely with participating contractors to exploit the use of the network analysis system. By 1962 the technique had received wide acceptance in contracting circles. The following example demonstrates the use of the PERT Time concept to aid in planning a construction project. The example was chosen to illustrate the PERT technique of network modeling and to show its value to a planner in visualizing a complex project.

Identification of activities.--In this example a contractor identified twenty-four activities that he felt would clearly define the total number of subtasks in the project.[7] The activities were listed in tabular form

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[6]U. S., Department of the Army, Engineer Regulation No. 1-1-11, op. cit., p. 1.

[7]U. S., Department of the Army, Office of the Adjutant General, "Department of the Army Letter on Management Practices," Letter AGAM-P(M) 310.1 (1 Nov 62) COMPT-M, 7 November 1962, Inclosure No. 2, p. 1.

(Table 2) and numbered sequentially for ease of identification on the network diagram. With this relatively few activities the manual technique was chosen to complete the analysis. Had fifty or more activities been required to describe the project, the contractor probably would have resorted to a computerized analysis of the procedure. Many computer centers in the United States offer this service at a rather nominal charge of 200 to 300 dollars.

Network Diagram.--Each proposed activity for the network diagram was analyzed in relation to the others. In laying out his diagram, the contractor first determined that activity which had to be started before any other task. An activity arrow was drawn on the left side of the paper and properly annotated (Figure 3). Next the second activity was laid out in graphical form. In visualizing this project the contractor saw that four activities could be started once the second activity had been completed. In Figure 3 these activities are shown as arrows 3, 4, 5 and 24. Subsequently the remainder of the project was drawn in on the network diagram. Each arrow was properly numbered.

Activity calculations.--Estimates of an expected time for each activity were calculated using the PERT Time concept of three time estimates (see Appendix B for a discussion of this type of calculation). In Table 2, columns 1, 2, 3 and 4 show the activity time estimates for the silo structure. The expected time is shown in column 5; in addition, it is also shown in Figure 3 above each activity arrow.

Path calculations.--The network diagram, Figure 3, has sixteen paths. The longest one, 345 days in length, was called the critical path and marked with a heavy black line. This path includes activities 1, 2, 3, 7 and 10. Each of the other paths is shorter and therefore has some

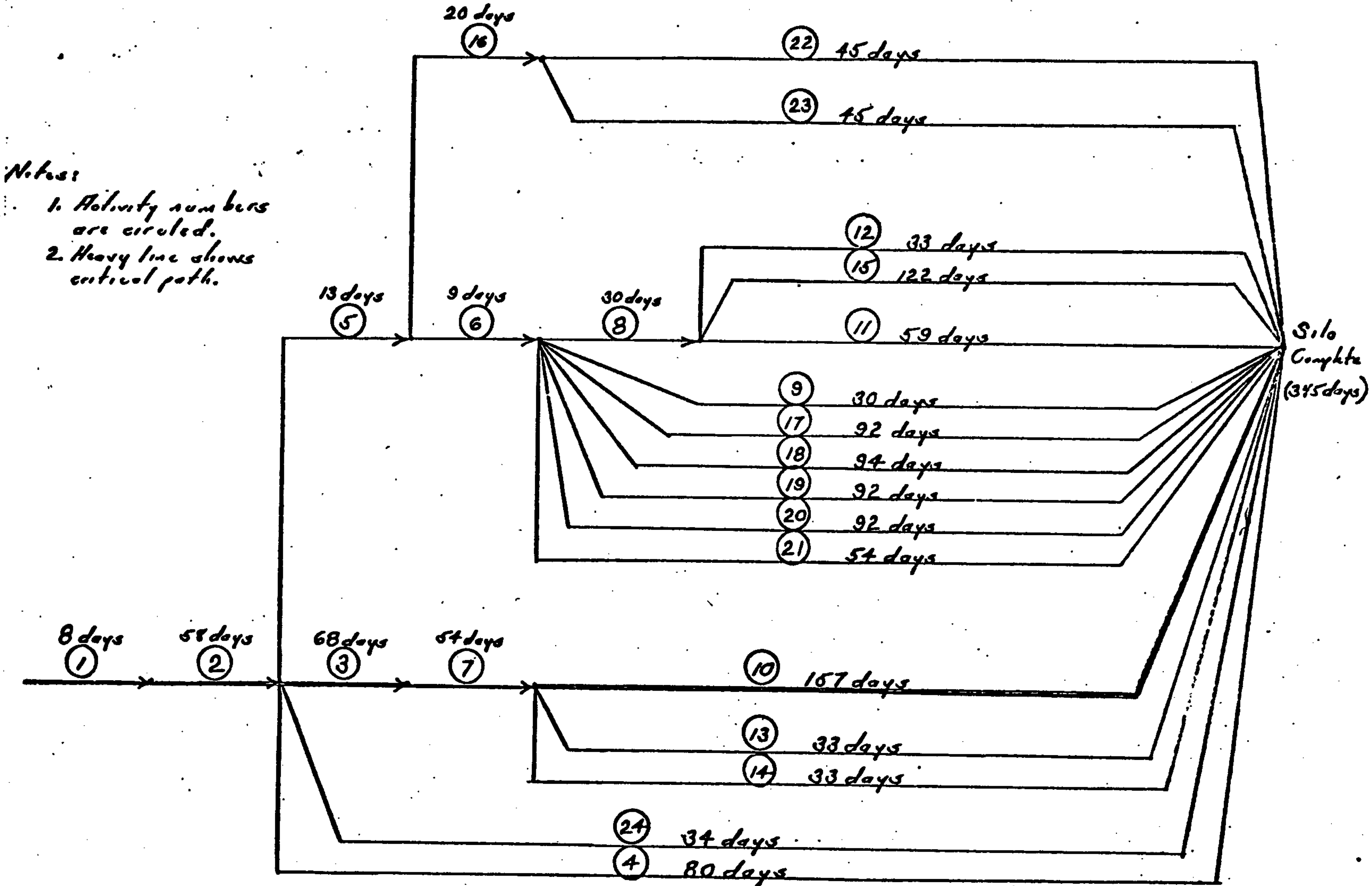
TABLE 2 Silo Construction—Network Calculations [8]

Activity No.	Construction or Installation Activity	Activity Calculations				Path Calculations			Probability Calculations			
		Optimistic Time 1	Most Likely Time 2	Pessimistic Time 3	Activity Time 4	Expected Time 5	Latest Time 6	Slack 7	Activity Variance 8	Cumulative Variance 9	Schedule Time 10	Probability 11
1	Excavation (Open cut)	6	8	10	8	8	8	0	0	0	7	0.0
2	Excavation (Silo)	52	56	70	58	66	66	0	9	9	64	0.25
3	Reinforcing Steel	60	68	74	68	134	134	0	5	14	125	0.01
4	Silo Concrete (Except Cap)	70	79	92	80	146	345	199	13	22	140	0.10
5	Collimator Embedded Plate	10	13	15	13	79	184	105	1	10	82	0.83
6	Crib Suspension System, Wall Bracket	8	7	11	9	88	193	105	0	10	90	0.74
7	Steel Crib	49	54	60	54	188	188	0	3	17	170	0.0
8	PLS Pressure Vessels	27	28	39	30	118	223	105	4	14	110	0.02
9	PLS Cryogenic Vessels	25	31	32	30	118	345	227	1	11	98	0.5
10	PLS Prefabs + Piping	140	160	163	157	345	345	0	15	32	320	0.0
11	Cable Trays	45	59	72	59	177	345	168	20	34	168	0.07
12	Compressed Air System	30	31	45	33	151	345	194	6	20	150	0.41
13	Elevator (Personnel)	29	30	50	33	221	345	124	12	29	230	0.96
14	Diesel Generator + Switchgear	30	33	37	33	221	345	124	1	18	210	0.01
15	Heating, Ventilating, Air Conditioning	101	119	157	122	240	345	105	87	101	235	0.31
16	Blast Closure	12	21	22	20	99	300	201	3	13	96	0.20
17	Launch Platform, guides + brackets	80	91	107	92	180	345	165	20	30	170	0.03
18	Launch Platform Counterweight	90	91	110	94	182	345	163	11	21	175	0.06
19	Launch Platform Drive Base	81	88	118	92	180	345	165	38	48	185	0.76
20	Launch Platform Drive Mechanism	77	91	112	92	180	345	165	34	44	192	0.96
21	Crib Suspension System, Spring	43	55	59	54	142	345	203	7	17	140	0.31
22	Silo Cap + Doors	36	46	44	45	144	345	201	5	18	135	0.02
23	CBR Filters	40	44	53	45	144	345	201	5	18	141	0.24
24	Electrical Conduit Wire + Fixtures	27	34	40	34	100	345	245	5	14	99	0.39

[8] Ibid., Exhibit I(Revised), p.5.

Fig 3.— Silo Construction
Network Showing Activity Times[9]

Notes:
1. Activity numbers are circled.
2. Heavy line shows critical path.



[9]Ibid., Exhibit II(Revised), p.6.

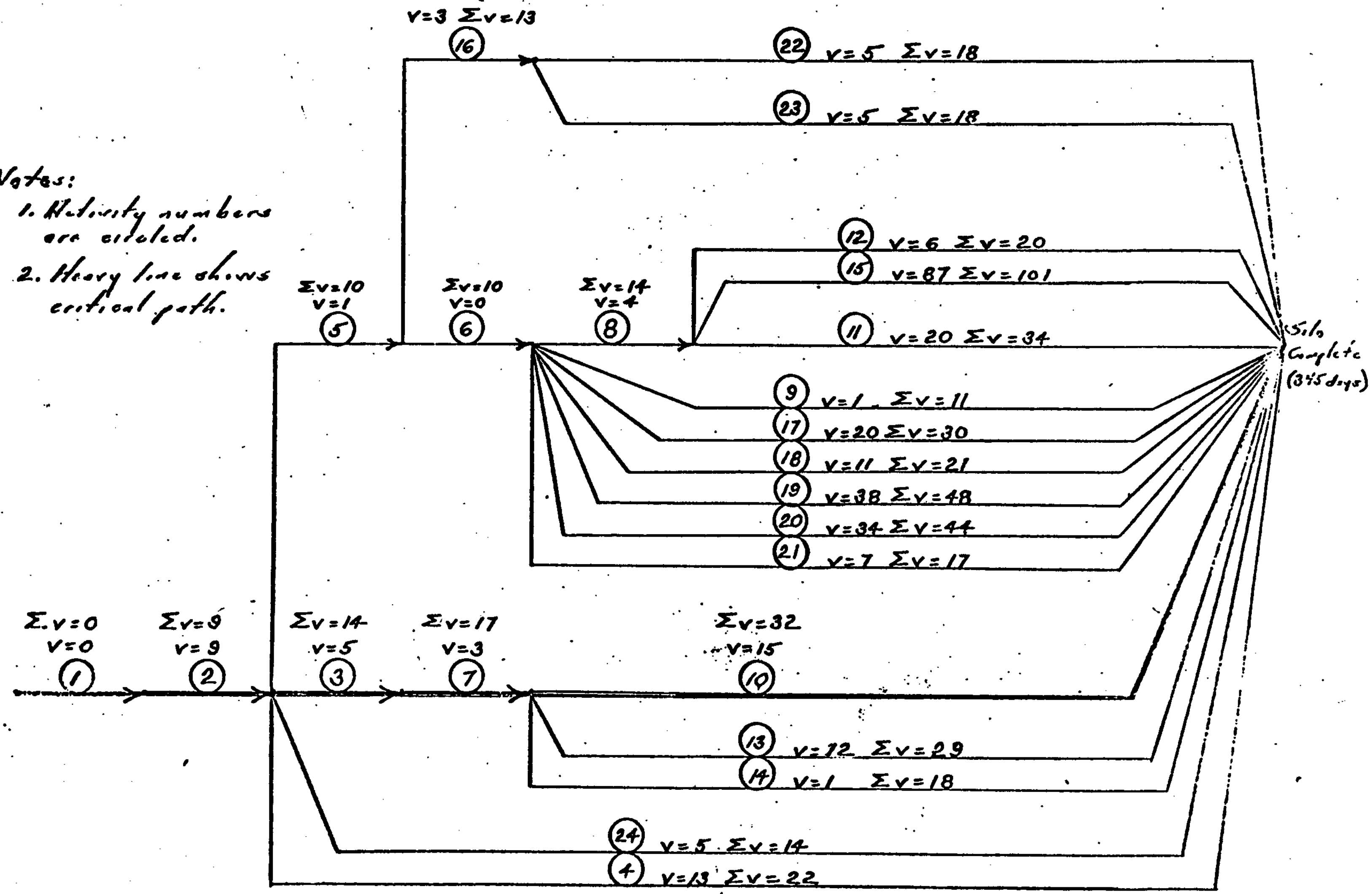
slack time. The slack time for each activity was next calculated through a few simple operations. First, the expected completion time for each activity was found by totalling activity times forward along a path to the activity under study. Column 5 of Table 2 lists the activity expected times. Next, each activity latest time was found by totalling in a backward direction along a path, to the activity under study, and subtracting this figure from the critical path length. In this project the critical path length is 345 days. When several paths branch out after completion of the activity under study, the length of the longest branch path must be used to determine the latest time (also called the latest allowable completion time) for the activity. Column 6 of Table 2 lists the activity latest times. Slack time for each activity was calculated by subtracting the expected time from the latest time. Slack time for each activity, in days, is shown in column 7 of Table 2.

Probability calculations.--The figures for the optimistic and pessimistic times for each activity were used to calculate the activity's variance (see Appendix B for a discussion of this calculation). Each variance is listed in column 8 of Table 2. In addition, a separate copy of the network diagram was used to show the activities' variances (Figure 4). The cumulative variance for each activity was then calculated by totalling activity variances forward along a path to the activity under study. Cumulative variances are listed in column 9 of Table 2 and are also shown in Figure 4.

A list of scheduled completion times was imposed upon the contractor; these dates are listed in column 10 of Table 2. The contractor made a comparison of scheduled completion times with the expected times, and expressed this analysis in terms of a probability of completing each

Fig.4.— SILO CONSTRUCTION
NETWORK SHOWING ACTIVITY AND CUMULATIVE VARIANCES[10]

Notes:
1. Activity numbers are circled.
2. Heavy line shows critical path.



10 *Ibid.*, Exhibit III (Revised), p.7.

activity by the scheduled date. The following procedure was used to calculate probability for each activity:

"(1) Take the square root of the accumulated variance.

"(2) Divide the difference between the expected and scheduled times by the square root of the accumulated variance.

"(3) Use this quotient to enter Table 3 and obtain a reading.

"(4) Subtract the reading from 0.5000 if the scheduled time is less than the expected time, or add the reading if the scheduled time is greater than the expected time."[11]

The probability of meeting each scheduled date is shown in column 11 of Table 2.

Analysis of the application.--This example of the network analysis system helps to show that projects which involve a limited number of activities can be satisfactorily analyzed when using the PERT Time concept with manual computations. The silo contractor might have sought ways to reduce the project expected completion time by applying additional resources to activities along the critical path. By considering available slack time in the other paths, the contractor could have transferred some resources to the tasks along the critical path.

Probability calculations serve to indicate the risks that are built into the project schedule. In this project the contractor noted that 320 days was an unrealistic scheduled completion time. His computations indicated that it was statistically improbable that the project would be completed in 320 days. Note in column 10 of Table 2 that the scheduled completion date for activity 10 is 320 days. This activity is the last one on the critical path; the probability of meeting this activity completion date is likewise the probability of completing the entire project within 320 days.

[11] Ibid., p. 2.

TABLE 3

AREAS UNDER THE NORMAL CURVE FROM A POINT P TO THE MEAN OF THE CURVE [12]

P ($\frac{x}{\sigma}$)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.0000	.0040	.0080	.0120	.0159	.0199	.0239	.0279	.0319	.0359
0.1	.0398	.0438	.0478	.0517	.0557	.0596	.0636	.0675	.0714	.0753
0.2	.0793	.0832	.0871	.0910	.0948	.0987	.1026	.1064	.1103	.1141
0.3	.1179	.1217	.1255	.1293	.1331	.1368	.1406	.1443	.1480	.1517
0.4	.1554	.1501	.1628	.1664	.1700	.1736	.1772	.1808	.1844	.1879
0.5	.1915	.1950	.1985	.2019	.2054	.2088	.2123	.2157	.2190	.2224
0.6	.2257	.2291	.2324	.2357	.2389	.2422	.2454	.2486	.2518	.2549
0.7	.2580	.2612	.2642	.2673	.2704	.2734	.2764	.2794	.2823	.2852
0.8	.2881	.2910	.2939	.2967	.2995	.3023	.3051	.3078	.3106	.3133
0.9	.3159	.3186	.3212	.3238	.3264	.3289	.3315	.3340	.3365	.3380
1.0	.3413	.3438	.3461	.3485	.3508	.3531	.3554	.3577	.3599	.3621
1.1	.3643	.3665	.3686	.3708	.3729	.3749	.3770	.3790	.3810	.3830
1.2	.3849	.3869	.3888	.3907	.3925	.3944	.3962	.3980	.3997	.4015
1.3	.4032	.4049	.4066	.4083	.4099	.4115	.4131	.4147	.4162	.4177
1.4	.4192	.4207	.4222	.4236	.4251	.4265	.4279	.4292	.4306	.4319
1.5	.4332	.4345	.4357	.4370	.4382	.4394	.4406	.4418	.4430	.4441
1.6	.4452	.4463	.4474	.4485	.4495	.4505	.4515	.4525	.4535	.4545
1.7	.4554	.4564	.4573	.4582	.4591	.4599	.4608	.4616	.4625	.4633
1.8	.4641	.4649	.4656	.4664	.4671	.4678	.4686	.4693	.4699	.4706
1.9	.4713	.4719	.4726	.4732	.4738	.4744	.4750	.4758	.4762	.4767
2.0	.4773	.4778	.4783	.4788	.4793	.4798	.4803	.4808	.4812	.4817
2.1	.4821	.4826	.4830	.4834	.4838	.4842	.4846	.4850	.4854	.4857
2.2	.4861	.4865	.4868	.4871	.4875	.4878	.4881	.4884	.4887	.4890
2.3	.4893	.4896	.4898	.4901	.4904	.4906	.4909	.4911	.4913	.4916
2.4	.4918	.4920	.4922	.4925	.4927	.4929	.4931	.4932	.4934	.4936
2.5	.4938	.4940	.4941	.4943	.4945	.4946	.4948	.4949	.4951	.4952
2.6	.4953	.4955	.4956	.4957	.4959	.4960	.4961	.4962	.4963	.4964
2.7	.4965	.4966	.4967	.4968	.4969	.4970	.4971	.4972	.4973	.4974
2.8	.4974	.4975	.4976	.4977	.4977	.4978	.4979	.4980	.4980	.4981
2.9	.4981	.4982	.4983	.4984	.4984	.4984	.4985	.4985	.4986	.4986
3.0	.49865	.4987	.4987	.4988	.4988	.4988	.4989	.4989	.4989	.4990
3.1	.49903	.4991	.4991	.4991	.4992	.4992	.4992	.4992	.4993	.4993

Note: MEAN IS ZERO
STANDARD DEVIATION IS 1.0

[12] Ibid., Exhibit IV, p.9.

Although it was not reported in the reference cited, the silo contractor probably applied additional resources to activity 10 in order to reduce its expected completion time. As reported in Table 2 this activity was expected to take 157 days to complete. It materially contributed to the critical path length of 345 days. The next longest path is just 240 days. Theoretically, the expected time of activity 10 could have been reduced by 105 days before another path in the network became critical.

Although the tool is difficult to fully understand at first glance, the PERT Time concept is an excellent approach to the technique of network analysis. It provides a manager with some feel for the risk that he builds into a project construction schedule. Notwithstanding this fact, the PERT network magnifies slack time in the network and draws the planner's attention to the critical path of activities.

A schedule could easily have been prepared from the network developed for the silo construction. To accomplish this, the network need simply be oriented to a horizontal time scale which accounted for all non-work days. The procedure is completed by laying the critical path arrows along the horizontal axis.

<u>Summary</u>.--The PERT approach to project planning and scheduling has proven to be a worthwhile technique in contract construction for the Corps of Engineers. Admittedly, the concept of multiple time estimates has questionable value in planning unfamiliar work. But, certainly when a planner is familiar with both the subtasks and the available resources, multiple time estimates serve a valid and useful purpose in project analysis and scheduling. Relating this concept to the theater of operations, it appears that the vagaries of the battlefield would make a

planner quite skeptical about using multiple time estimates to calculate the expected time for completing a task. To completely rule out the technique of multiple time estimates likewise seems unreasonable, but such a procedure must be judiciously applied in the theater of operations. In most instances a single time estimate will suffice.

Planning the Inspection of a Large Hydroelectric Generating Unit

In this operation the network analysis system was applied in an attempt to reduce both the time and manpower required to make a routine annual technical inspection of a large hydroelectric generating unit. Time was analyzed in terms of hours rather than days. Planners were particularly concerned with the cost of the manpower requirements, including overtime requirements.[13]

Identification of activities.--The Corps of Engineers planners identified twenty-seven subtasks in the inspection process. Placed in a logical sequence, the subtasks are listed in Table 4. The manpower requirements for each task are listed in column 3, and the estimate of time to accomplish each is shown in column 2.

The dummy activities shown in Table 4 are used to show the dependency of activity 18-19 on six earlier subtasks.

Network diagram.--The planners visualized that the inspection project would be completed in the sequence shown in Figure 5. Each activity arrow is separated by a numbered event. This graphical numbering technique is a permissable convention although it differs somewhat from the technique

[13]U. S., Department of the Army, Engineer Regulation No. 1-1-11, op. cit., App. III, p. 3.

TABLE 4 CLARK HILL NETWORK ANALYSIS —RESOURCE REQUIREMENTS [14]

1 JOB	DESCRIPTION	2 TIME	3 MEN	4 REG COST	5 O/T COST
0-1	Warm Up Unit - Operate on System	2.5	-	-	-
1-2	Unwater & Clear Out	3.0	1-2	$11.13	$13.20
2-3	Open Bus Ducts	0.5	2	4.05	4.78
2-4	Open Penstock	0.5	2	4.05	4.78
2-5	Change Governor Oil	4.0	2	32.28	38.24
2-6	Dewater & Inspect Draft Tube	3.0	3	33.93	40.20
3-7	Gen Air Blast Breaker - Clean & Insp	2.0	3	22.62	26.80
3-8	Gen Neutral ACB - Clean & Inspect	2.0	2	16.14	19.12
3-9	Measure Gen Air Gaps	1.0	2	8.07	9.56
3-10	Headgates - Megger & Check Controls	1.5	2	12.10	14.34
3-11	Megger Auxiliary Equipment	2.0	2	16.14	19.12
3-12	Megger Stator, Field, Main & Pilot Exc	4.0	2*	39.84	36.20
3-13	Install Scroll Case Lighting	1.0	2	8.07	9.56
4-13	Install Scaffold	1.5	4	19.11	23.84
5-18	Dummy	-	-	-	-
6-19	Remove Draft Tube Gates	2	3	22.62	26.80
7-18	Dummy	-	-	-	-
8-18	Dummy	-	-	-	-
9-18	Dummy	-	-	-	-
10-18	Dummy	-	-	-	-
11-18	Dummy	-	-	-	-
12-14	Main Field - Clean for Pole Drop Test	3.0	2	24.21	28.68
12-18	Exciters & Cubicle - Clean & Inspect	3.0	2	24.21	28.68
13-15	Turbine Gate Clearances	5.0	2	40.35	47.80
14-16	Pole Drop Test	2.0	3**	25.80	25.06
15-17	Cavitation Measurements - Grease Check, Piezometer Checks, etc.	5.0	2	40.35	47.80
16-18	Inspect Rotor & Stator - Visual	1.0	2	8.07	11.31
17-18	Gov Rundown - Pump Settings, Strokes, etc.	6.0	3	67.86	80.40
18-19	Tripping Tests	2.0	2-3	19.92	18.10
19-20	Remove Clearance & Water Up	4.0	1-2	22.68	35.20
20-21	Run Governor Stabilization Chart	1.0	3	11.31	13.40
21-22	Perform Overspeed Test	0.5	2	4.05	4.78
22-23	Voltage Regulator Checks	0.5	2*	4.98	4.52

* 1 Elec, 1 Engr - Test Branch
** 2 Elec, 1 Engr - Test Branch

[14] Ibid., TABLE 2.

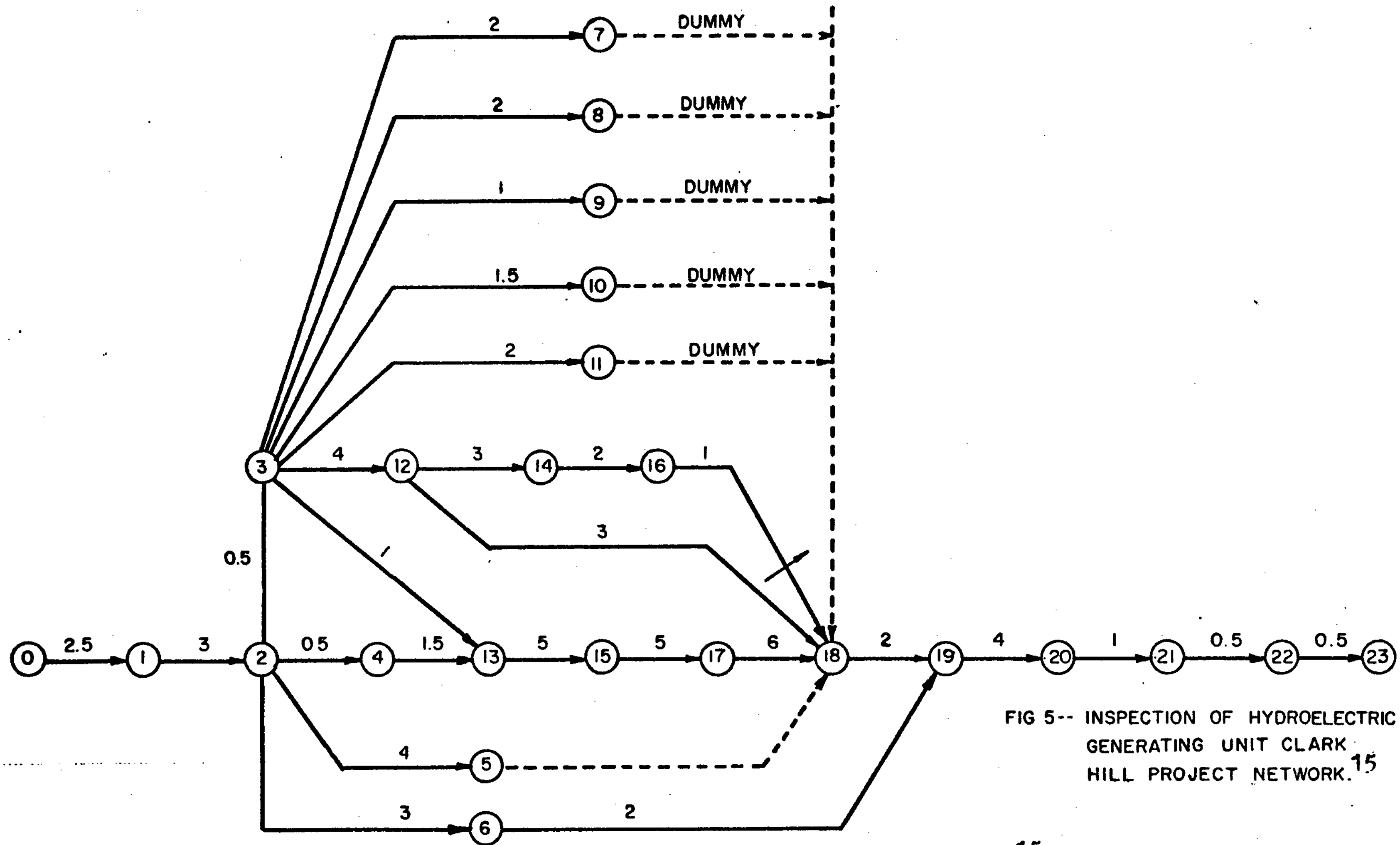


FIG 5-- INSPECTION OF HYDROELECTRIC GENERATING UNIT CLARK HILL PROJECT NETWORK.[15]

[15] Ibid., Fig. III-10.

used in the missile silo network. The time estimate for each activity is shown above the activity arrow.

Activity time estimates.--Figure 5 was next analyzed to establish the time estimates for each activity. These estimates are shown in Table 5. In addition, slack time was computed for each activity that is not on the critical path. Note in Figure 5 that the critical path is shown by laying it out on the horizontal axis.

Time-scaled network.--As the next step in the network analysis, planners prepared a time-scaled network to forecast manpower application; the network and man-loading diagram is shown in Figure 6. This preliminary man-loading plan did not satisfy the planners. It revealed that twenty-four men would be required to accomplish the inspection. However, this number of men was required only for a short time during the early stages of the inspection. The big jump in manpower requirements came because six activities were started when event 3 had taken place.

Figure 6 was modified to take advantage of the slack time that was available in nine of the network paths. In Figure 7 note that several activities were scheduled later in the inspection process. By distributing these subtasks evenly throughout the job the planners significantly reduced the total manpower requirement.

Analysis of the application.--In this application of the network analysis system planners reduced manpower requirements from twenty-four men to an inspection crew of six men, plus three specialists that would be hired for only a short duration.

At first glance the inspection of a power plant appears to be much too simple a task to warrant the use of the network analysis system. Yet even so simple a job as this was more easily visualized and planned

TABLE 5

CLARK HILL NETWORK ANALYSIS –TIME ESTIMATES[16]

1 JOB	DESCRIPTION	2 TIME	3 E.S.	4 E.F.	5 L.S.	6 L.F.	7 SLACK
0-1	Warm Up Unit - Operate on System	2.5	0	2.5	0	2.5	0
1-2	Unwater and Clear Out	3.0	2.5	5.5	2.5	2.5	0
2-3	Open Bus Ducts	0.5	5.5	6.0	5.5	6.0	0
2-4	Open Penstock	0.5	5.5	6.0	5.5	6.0	0
2-5	Change Governor Oil	4.0	5.5	9.5	21.5	25.5	16
2-6	Dewater and Inspect Draft Tube	3.0	5.5	8.5	20.5	23.5	15
3-7	Gen Air Blast Breaker - Clean & Inspect	2.0	6.0	8.0	21.5	23.5	15.5
3-8	Gen Neutral ACB - Clean & Inspect	2.0	6.0	8.0	21.5	23.5	15.5
3-9	Measure Gen Air Gaps	1.0	6.0	7.0	22.5	23.5	16.5
3-10	Headgates - Megger & Check Controls	1.5	6.0	7.5	22.0	23.5	16.0
3-11	Megger Auxiliary Equipment	2.0	6.0	8.0	21.5	23.5	15.5
3-12	Megger Stator, Field, Main & Pilot Exciters	4.0	6.0	10.0	13.5	17.5	7.5
3-13	Install Scroll Case Lighting	1.0	6.0	7.0	6.5	7.5	0.5
4-13	Install Scaffold	1.5	6.0	7.5	6.0	7.5	0
5-18	Dummy	-	9.5	23.5	23.5	23.5	14
6-19	Remove Draft Tube Gates	2	8.5	10.5	23.5	25.5	15
7-18	Dummy	-	8.0	23.5	23.5	23.5	0
8-18	Dummy	-	8.0	23.5	23.5	23.5	15.5
9-18	Dummy	-	7.0	23.5	23.5	23.5	16.5
10-18	Dummy	-	7.5	23.5	23.5	23.5	16.0
11-18	Dummy	-	8.0	23.5	23.5	23.5	15.5
12-14	Main Field - Clean for Pole Drop Test	3.0	10.0	13.0	17.5	20.5	7.5
12-18	Exciters & Cubicle - Clean & Inspect	3.0	10.0	13.0	20.5	23.5	10.5
13-15	Turbine Gate Clearances	5.0	7.5	12.5	7.5	12.5	0
14-16	Pole Drop Test	2.0	13.0	15.0	20.5	22.5	7.5
15-17	Cavitation Measurements - Grease Check, Piezometer Checks, etc.	5.0	12.5	17.5	12.5	17.5	0
16-18	Inspect Rotor & Stator - Visual	1.0	15.0	16.0	22.5	23.5	7.5
17-18	Gov Rundown - Pump Settings, Strokes, etc.	6.0	17.5	23.5	17.5	23.5	0
18-19	Tripping Tests	2.0	23.5	25.5	23.5	25.5	0
19-20	Remove Clearance & Water Up	4.0	25.5	29.5	25.5	29.5	0
20-21	Run Gov Stabilization Chart	1.0	29.5	30.5	29.5	30.5	0
21-22	Perform Overspeed Test	0.5	30.5	31.0	30.5	31.0	0
22-23	Voltage Regulator Checks	0.5	31.0	31.5	31.0	31.5	0

E.S. Earliest Start

E.F. Earliest Finish

L.S. Latest Start

L.F. Latest Finish

SLACK - The time any given job may be delayed before it affects project completion time. Subtract Earliest Finish, E.F., from Latest Finish, L.F.

16 *Ibid.*, TABLE 3.

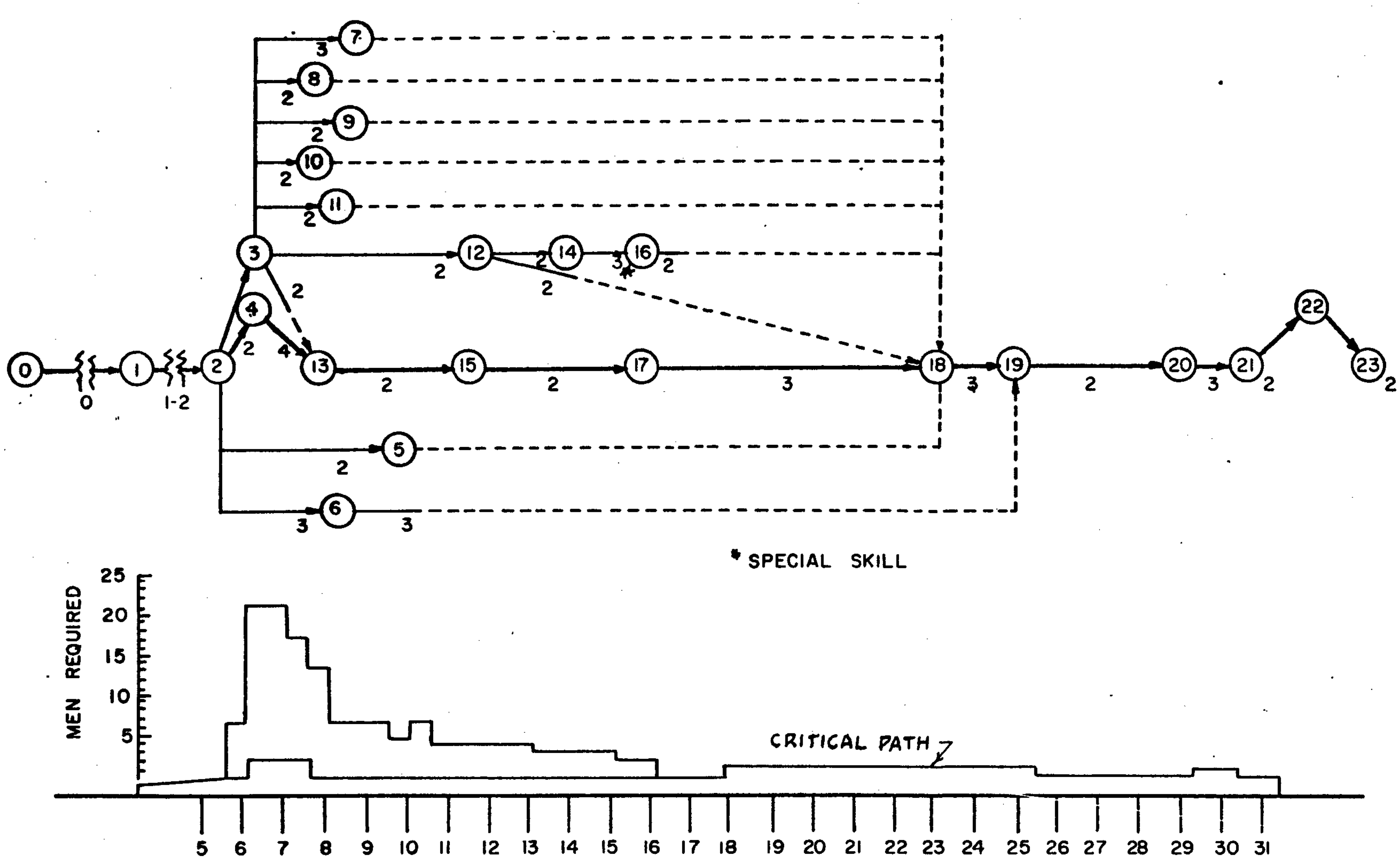


FIG 6-- INSPECTION OF HYDROELECTRIC GENERATING UNIT CLARK HILL PROJECT[17]
PRELIMINARY TIME SCALED NETWORK AND MAN-LOADING DIAGRAM.

[17] Ibid., Fig. III-11.

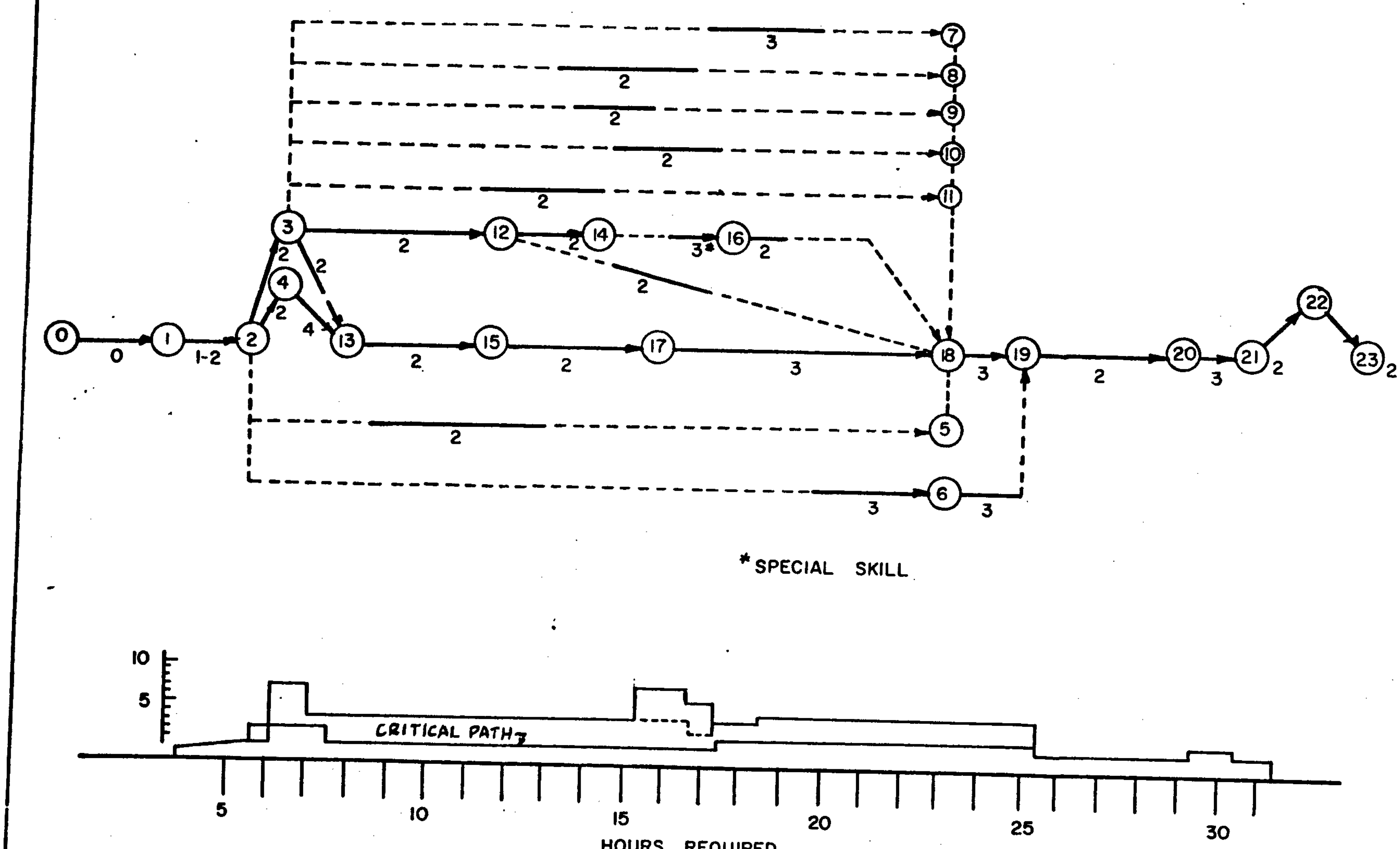


FIG 7--INSPECTION OF HYDROELECTRIC GENERATING UNIT CLARK HILL PROJECT FINAL TIME-SCALED NETWORK AND MAN-LOADING DIAGRAM.[18]

[18] Ibid., Fig. III-12.

through the networking technique. Not only was the manpower requirement significantly reduced, but many hours of time were saved by this graphical analysis of the inspection process. The report of this analysis noted that the inspection time took about fifty-six hours during the previous year's inspection.[19] When the analysis was completed, the final schedule reflected an inspection time of about thirty-two hours.

Summary

The Corps of Engineers has demonstrated that the network analysis system is a very useful tool for planning and scheduling field work. The procedure is quite versatile and has many applications.

Contractors have used the networking technique to their advantage on numerous government projects. In general, networking aided planners to properly identify all project subtasks, to simplify scheduling and to forecast problem areas before they occurred. Networking improved the work efficiency and reduced project duration.

The network analysis system has been introduced in planning for engineer field operations. In a very limited way, at least, both Seventh and Eighth Army engineers now use the technique to aid in planning engineering tasks.

The network analysis system has been publicized within the Corps of Engineers for about three years. Each day new applications are found which demonstrate the broad applicability of the system.

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[19]<u>Ibid</u>., p. 3.

CHAPTER III

THE FUNCTIONS OF THE FIELD ARMY ENGINEER

Introduction

Accounts of engineer assistance to the American Army in the field date back to the time of the Revolutionary War. Through the years the engineer has become identified as a special staff officer in the field army at division and higher levels.

In 1940, as the threat of war hung over the North American Continent, the War Department published what might be termed the modern-day concept of the engineer's functions. Basically, the engineer was made responsible to plan, schedule and control all engineer activities in the command. His supervisory role was limited within the guidance prescribed by the commander. However, he was expected to plan all construction and destruction activities undertaken in the field. He became his own supply officer. Surveying and mapping remained a part of his job. And, he was expected to perform technical inspections of captured engineer equipment. He was the camouflage expert for the command. In addition, he was responsible for the reconnaissance of roads and bridges and assisted in preparing highway signs and formulating other traffic regulations.[1]

The engineer was the chief advisor to the commander and staff on engineer matters. He entered World War II as a special staff officer. In contrast with this status, the engineer in the field army soon found

1U. S., War Department, Staff Officer's Field Manual, FM 101-5 (Washington: U. S. Government Printing Office, August 19, 1940), pp. 21-22.

that he had many responsibilities that required him to command engineer troop units. One simple answer to the problem was published in February 1943. In rewriting Army Regulation 100-5, the Army directed that the engineer, under the direction of his commanding officer, would command those engineer troops assigned to the unit that were not further assigned to a subordinate commander.[2]

The matter of command versus staff functions seemed to be settled. However, the following year Field Manual 5-6, changes number 4, stated that in corps and higher echelons, the engineer would act only as a special staff officer and have no command function.[3]

In January 1948 Army doctrine once again modified the command function of the corps and field army engineers. In addition to their staff functions, each was given the responsibility to command all engineer troops not assigned or attached to subordinate echelons.[4] Today the engineer at division and higher echelons is both a staff officer and a commander.

The overall role of the army engineer has kept pace with modern technological advances. Functions spelled out in the 1940 edition of Field Manual 101-5 have been updated in both terminology and substance. For example, today the engineer assists the commander in planning for the

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[2]U. S., War Department, Corps of Engineers, General Provisions, AR 100-5 (Washington: U. S. Government Printing Office, February 12, 1943), p. 3.

[3]U. S., War Department, Engineer Field Manual, Operations of Engineer Field Units, FM 5-6 (Washington: U. S. Government Printing Office, April 23, 1943 with changes no. 4, 16 December 1944), par. 3b.

[4]U. S., Department of the Army, FM 5-6, loc. cit., changes no. 6, 21 January 1948, par. 3b.

use of atomic demolition munitions.[5] World War II provided a wealth of experiences upon which current doctrine is based. In the European Theater six armies were fielded by the United States. In the Pacific three armies were activated.

Fortunately engineers as a group are quite prone to write about their experiences; and, for the most part a researcher will discover that the operations of engineers in World War II were well documented.

World War II Functions

General

In World War II combat engineers provided close support to the tactical units by providing the general functions of construction and destruction. This support was echeloned from the front lines to the field army rear boundary, thus it embraced the entire Combat Zone.

When a Communications Zone existed behind the Combat Zone engineers assigned to the Advance Section (ADSEC) worked closely with the field army engineers. Often the ADSEC engineers worked forward into the Combat Zone constructing ports, railroads, power lines and petroleum distribution facilities.[6] The theater policy emphasized that engineer support would be pushed forward aggressively into the area of the next lower engineer, by the higher engineer. But notwithstanding this was

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[5] U. S., Department of the Army, Engineer Troop Organizations and Operations, FM 5-1 (Washington: U. S. Government Printing Office, May 1961), p. 18.

[6] U. S., Forces, European Theater of Operations, Communications Zone, Advance Section, Engineer Section, "Activities Report of Engineer Section," 13 July 1945, p. 1.

the policy that each engineer was responsible for the accomplishment of all work in his area.[7]

Engineer Work in the European Theater

General.--In the European Theater of Operations engineer support was provided by one of two methods--area support or task assignment. Generally support was provided on an area basis by establishing an "engineer work boundary" that was usually forward of the administrative boundary. However, at times it was more practical to provide support on a task basis. In this latter case the engineer at the higher echelon assumed full responsibility for the completion of the task.[8]

Support at the division level.--The division engineer performed a dual role. Doctrinally he was the engineer special staff officer to the division commander and also commanded the engineer troops assigned or attached to the division.

The division engineer was an operator who performed many diversified functions; the following are representative:

(1) Coordinated all engineer combat support within the division.

(2) Commanded and supervised all engineer troops within the division. Normally one engineer combat battalion was organic to each division.

(3) Advised the commander and staff on all engineer matters.

(4) Provided engineer intelligence, engineer supplies, water and maps.

(5) Recommended action to obtain engineer support from the corps and army engineers.

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[7]U. S., Forces, European Theater of Operations, The General Board, "Reports of the General Board," Study No. 72, 20 December 1946, Chapter 7, p. 39.

[8]*Ibid.*

(6) Prepared the engineer portions of division plans and orders.[9]

Division engineer troops performed many tasks. Usually they were placed in direct support of the regimental combat teams. Yet, at times they were attached to the infantry and armored units to enhance the overall control of an operation. The following list contains typical divisional engineer functions that were performed in the European Theater:

(1) Maintenance of roads and bridges.

(2) Construction and removal of obstacles and mine fields.

(3) Support of assault units in river-crossing operations.

(4) Assistance in preparation of defensive positions.

(5) Commitment as infantry.[10]

Support at the corps level.--The corps engineer generally performed a dual role of both commander and staff engineer. He had few administrative functions and spent the majority of his time engaged in providing close engineer support to the committed divisions. In addition he had an area responsibility, for he coordinated all engineer work in the corps service area.

The corps engineer worked quite closely with the army engineer, often conducting limited operational planning in conjunction with field army engineer planning.[11]

Several types of engineer units were normally attached to each corps;

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[9]William A. Carter, Jr., "Employment and Staff Procedures of Engineers with Division, Corps and Army" (lithographed, 15 March 1946) (Colonel Carter was the First Army Engineer from May 1944 through October 1945), p. 2.

[10]*Ibid.*, p. 6.

[11]*Ibid.*, pp. 13-18.

some of these included engineer group headquarters, combat battalions, light ponton companies, heavy ponton companies, treadway bridge companies, light equipment and dump truck companies, and a topographic company.

The corps engineer further attached his engineer units to the commanders of the engineer group headquarters. The groups normally received and accomplished area type missions. They supported the committed divisions by constructing all tactical bridges, maintaining the main supply routes, preparing defensive positions, and executing some general construction.[12]

Support at the field army level.--On the plains of northern Europe the field army engineer habitually directed the efforts of the engineer units that were not further assigned or attached to the corps or divisions.[13]

Aside from this command function, the army engineer was the principal advisor to the commander on engineer matters and served on his special staff. Perhaps his major function was to plan engineer effort required for future operations. Supply requirements were directly related to operational planning and he logically directed the procurement, storage, and issue of engineer supplies to all army units.

Each army engineer staff section was modeled after the prescribed table in TOE 200-1. By late 1944 the table was amended and the engineer section was expanded to an authorization of twenty-nine officers and forty-three enlisted men.[14] Army Field Manual 5-5 prescribed the following army engineer staff organization:

(1) Command: The army engineer and his executive officer.

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[12] Ibid. [13] Ibid., p. 30.

[14] U. S., War Department, Headquarters Army, TOE 200-1 (Washington: U. S. Government Printing Office, 26 October 1944).

(2) Executive Staff:

(a) Administration and Personnel Section.

(b) Intelligence and Map Section.

(c) Operations and Training Section.

(d) Transportation and Supply Section.

(3) Engineering Staff:

(a) Roads Section.

(b) General Construction Section.

(c) Miscellaneous Field Engineering Section.[15]

The staff organization prescribed for the army engineer section was modified somewhat by each of the army commanders in the field. Generally the size of the engineering staff was increased and in some cases the functional breakdown of the staff was remarkably changed.

The army engineer had an area type combat support mission to perform in the army service area, yet his engineer units backed up the corps engineers with close and continuous support. From one to several engineer combat groups operated under the army engineer. In addition, he had an engineer service group to provide supply and maintenance services, trucking services, and additional bridging capability.[16]

It's not surprising to see that the army engineer augmented his authorized staff, because, besides controlling several engineer group activities, he also had several miscellaneous units under his direct control. These units performed a host of special services, such as

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[15] U. S., War Department, Engineer Field Manual, Engineer Troops, FM 5-5 (Washington: U. S. Government Printing Office, 11 October 1943, with changes no. 4, 18 November 1944), par. 23.

[16] Carter, op. cit., pp. 36-37.

operation of the army map depot, topographic services, camouflage assistance, water supply, field surveying, and fire fighting.

Each of the nine overseas field army engineers developed his own approach for executing his command and staff functions. The engineer staffs were organized for work in order to face the unique coordination and control functions that existed in their respective theaters.

Presented in the following sections are brief outlines of some aspects of field army engineer operations in wartime. No attempt is made to present a comprehensive summary of the army engineer history; to do so would require a separate paper, which is beyond the scope of this thesis. Viewed as a group the following accounts of army engineer functions help to provide a clearer understanding of just what this engineer does in a theater of operations.

The First Army Engineer.--The First Army Engineer, Col. William A. Carter, Jr., modeled his staff after the guide in Field Manual 5-5. However, he added a separate map section and relieved the intelligence section of this function.[17]

Colonel Carter was a proponent of sound and complete operational planning. He provided his staff with detailed check lists to aid them in preparing estimates and operation plans.

The selection and establishment of the Army Road Net was an important and time consuming task.[18]

He assigned work to his engineer combat groups on an area basis and used a special radio net to speed the transmission of orders.

Road maintenance was a major task for the army engineer troops.

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[17] Ibid., p. 30.

[18] Ibid., p. 58.

When the First Army exploited the St. Lo breakthrough in August 1944 about 62 percent of the engineer effort was devoted to road and bridge work.[19]

By January 1945 army engineer units were occupied in the replacement of bridges, removal of obstacles, winterization of hospitals and road maintenance.[20] Several gravel pits and saw mills were operated in support of these operations.

The S-3 Section prepared plans for many engineer projects, and kept the plan for the Army Road Net up to date. Engineering designs were completed for bridges, buildings, and prisoner of war stockades.

The First Army crossed the Rhine River on 6 March 1945. Engineer advance planning for the operation was begun in September 1944 and continued until the Rhine River was crossed.[21] Much of the advance planning was focused on the identification of supply requirements that could not be met in the theater.

Colonel Carter, with a staff of thirty-three officers and fifty-one enlisted men, had operational command of four engineer combat groups and one engineer service group.[22]

The Third Army Engineer.--Brig. Gen. John F. Conklin, the Third Army Engineer, had close control over his army engineers. He issued orders

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[19] U. S., Forces, European Theater of Operations, First Army, Engineer Section, "After Action Report, First Army, 1-31 Aug 44, Engineer," n. d., p. 2.

[20] U. S., Forces, European Theater of Operations, First Army, "After Action Report, First Army, 1-31 January 1945," Appendix 2 to Sec III, 21 Apr 45, p. 77.

[21] U. S., Forces European Theater of Operations, First Army, Office of the Engineer, "Report of the Rhine River Crossing," May 1945, p. 43.

[22] Carter, op. cit., p. 36.

directly to his troops in the name of his commander. His problems were comparable with those of the First Army. That is, he was under constant pressure to keep the lines of communication open and provide close support to the rapidly advancing Third Army.

In January 1945 the Third Army was responsible for 11,000 miles of road. By March 1945 there was a serious shortage of engineer troops. General Conklin finally resorted to the use of prisoners of war, quartermaster truck companies, civilians, and an engineer general service regiment to augment his army engineers in road maintenance operations.[23]

In river crossing operations army engineer troops followed behind the corps engineers to help expand the crossing sites. Army engineers constructed semi-permanent type timber bridges to replace the corps tactical bridges.[24]

The Ninth Army Engineer.--The Ninth Army Engineer, Brig. Gen. R. U. Nicholas, exercised operational control over all assigned engineer troops that were not further assigned or attached to subordinate units.

His army engineer section was established with seven sections--S-1, S-2, S-3, S-4, Roads, General Construction, and a Map Section.[25] Engineer planning was conducted by the Roads and General Construction

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[23]U. S., Forces, European Theater of Operations, Engineer Service, Final Report of the Engineer, European Theater of Operations, 1942-1945 (Paris: Horne Et Fils, 1949) Vol. I, Secondary source material was cited because primary source material could not be located to support the statement, p. 299.

[24]U. S., Forces, European Theater of Operations, Third Army, Office of the Engineer, "Functions of the Army and Corps Engineers in River Crossing Operations," Letter EO.800 GNMCR-5, Hq, Third Army, 31 July 1945.

[25]U. S., Forces, European Theater of Operations, Ninth Army, Engineer Headquarters, "Standing Operating Procedures, Army Engineer Headquarters," 8 July 1944.

Sections. In addition, these two sections assisted the army engineer in project control--they inspected projects, maintained progress charts, and tabulated report data.[26]

Extensive operational planning occurred in the army engineer section prior to each new army operation, general movement or regroupment.[27] Ninth Army engineer planning for the Rhine River crossing of March 1945 is discussed in some detail in Chapter VI of this paper.

The Fifteenth Army Engineer.--The Fifteenth Army became operational on 30 March 1945 when it took over that portion of the First and Ninth Army areas west of the Rhine River.[28] The army engineer staff engaged in several aspects of planning; these included, preparation of a barrier plan for the Rhine River, compilation of road and bridge data, evaluation of engineer intelligence, and planning for the redeployment of engineer supply depots.[29] [30] As the war in Europe drew to a close the army engineer directly controlled about 2,000 engineer troops; the remainder were under the control of the corps engineers.[31]

Engineer Work in the Mediterranean Theater

The Fifth Army Engineer.--The Fifth Army Engineer Section was organized in January 1943 under the direction of Col. Frank O. Bowman.

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[26] *Ibid.*, pp. 4-6. [27] *Ibid.*, p. 6.

[28] U. S., Forces, European Theater of Operations, Fifteenth Army, "Fifteenth Army After Action Report, Period 30 March-30 April 1945," Sec. III, p. 1.

[29] *Loc. cit.*, inclosure no. 6, p. 1. [30] *Ibid.*, p. 4.

[31] U. S., Forces, European Theater of Operations, Fifteenth Army, "Fifteenth Army After Action Report, Period 1-31 May 1945," Engineer Section, p. 1.

From this time until the army landed on the coast of Italy in September 1943 the engineer section conducted extensive operational planning.[32] Several plans were prepared to support landings at various places in the vicinity of Sardinia and Italy. However, only the plan for the landing at Salerno was executed.[33]

Engineer plans for this operation, called Operation AVALANCHE, presented a detailed analysis of engineer supply requirements. The planners spent considerable time analyzing the landing beaches, exit routes inland, and the nearby airfields.[34] Engineer intelligence officers provided the commander with information on the landforms, communication net, water supply, and port facilities.

In Operation AVALANCHE the army engineer supported a two-corps attack (with nine divisions engaged in securing the Salerno bridgehead). Two engineer general service regiments and several separate units participated under the command of the army engineer.[35]

Colonel Bowman controlled his engineer resources through a small, closely knit staff. He chose for his staff men with wide experience and versatility. He felt that senior planners had to be familiar with engineer logistics, intelligence, and engineer troop units.[36]

The army engineer habitually prepared plans which searched deep into the enemy rear areas. Supply requirements were broad in nature; yet, as forecasts, they permitted timely requisitioning for the future operations.

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[32]U. S., Forces, Mediterranean Theater, Fifth Army, Engineer Section, "Engineer History, Fifth Army, Mediterranean Theater," vol. I, 1945, p. 3.

[33]_Ibid._ [34]_Ibid._, p. 4. [35]_Ibid._, p. 5.

[36]U. S., Forces, "Engineer History, Fifth Army, Mediterranean Theater," _loc. cit._, vol. II, p. 265.

Several categories of plans were developed in the army engineer section; they included the following aspects:

(1) Advice to the commander and staff on future operations--terrain studies, estimates of requirements and route analyses.

(2) Studies of river-crossing sites, routes and obstacles.

(3) Long-range studies to identify logistical requirements.

(4) Preparation of engineer operation plans.[37]

The Seventh Army Engineer.--The Seventh Army planned and successfully executed the liberation of Sicily early in 1943. Engineer operational planning was detailed and well coordinated. The army engineer, Col. Garrison H. Davidson, started his planning efforts by making several assumptions. For example, he assumed that army engineers would provide all necessary repair and construction in Palermo Harbor through D+60.[38] Estimates were then made to forecast the workload. Aerial photographs helped considerably. Missions were tentatively drawn up and a list of required engineer units was prepared. In addition, a chronology was made to plan the phased transfer of responsibility between various engineer units. Finally an engineer troop list was prepared.[39]

Colonel Davidson's Supply Section drew up supply requirements for such items as Bailey Bridge sets, mine detectors, and bulk fuel storage tanks.

The engineer plan for the Sicilian campaign contained the following

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[37]William P. Jones, Jr., "Engineer Planning at Field Army Level," The Military Engineer, Nov-Dec 61 (the author was chief of Colonel Bowman's planning staff in Italy), pp. 442-43.

[38]U. S., Forces, Mediterranean Theater, Seventh Army, Office of the Engineer, "Engineer Report, Sicilian Campaign," 18 September 1943, p. 1.

[39]Ibid., p. 5.

rather comprehensive aspects:

(1) Assumptions, based upon a phased tactical situation.

(2) Missions and major tasks to be accomplished.

(3) Organization of the army engineer section.

(4) Task organization for engineer troops.

(5) Control matters.

(6) Lists of equipment that would probably be captured intact.

(7) The construction outline plan which gave project assignments and supply data.

(8) Miscellaneous guidance on the use of labor, funds, real estate, and supplies.[40]

Engineer Work in the Southwest Pacific Area

General.--The limited army size operations in the Southwest Pacific Area during World War II were in contrast with the large land-mass army operations of the European Theater. In the Pacific the war was fought as a series of island-hopping campaigns.

The engineer planning and control functions had slightly different aspects in this area compared with those functions previously discussed. In the Pacific the army engineer provided mostly advance planning, and rarely influenced the action once an operation commenced. Assault forces no larger than a corps was the norm. And, the combat support of tactical forces was controlled by either a corps or division engineer.

Seldom an operator, and even less frequently a commander, the army engineer devoted a good deal of his effort to operational planning and logistics.

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[40]U. S., Forces, Mediterranean Theater, Seventh Army, loc. cit., inclosure no. 1.

Each objective area was somewhat unique from all others. As a result, detailed plans were required and supplies had to be identified by quantity, type, and in a specific order for arrival.[41] Staging and resupply areas were generally located several hundreds of miles from an objective area. In many operations Liberty ships provided floating supply stocks.

The Sixth, Eighth and Tenth U. S. Armies operated in this area in 1944 and 1945. Some accounts of the army engineer activities are discussed below.

The Sixth Army Engineer.--The Sixth Army made the first landing in the Philippines near Tacloban on Leyte Island on 20 October 1944.[42] The landing site was 1,500 miles from the nearest engineer supply base--in New Guinea. To compound the logistics problem, army engineers had only one month to plan for the operation.

Two fundamental missions had to be planned for the Leyte operation--construction of airstrips with other base development, and support of the tactical forces.[43] The final engineer plan was unique in that it made a special point of phasing engineer troop units into the objective area.

Engineer troop units employed on Leyte included one amphibious brigade, twenty-five construction battalions and about forty separate

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[41] U. S., Forces, Southwest Pacific Area, Sixth Army, Report of the Luzon Campaign, 9 January 1945-30 June 1945, vol. IV, Engineer, n. d., p. 22.

[42] Ibid., p. 1.

[43] S. D. Sturgis, Jr., "Engineer Operations in the Leyte Campaign," Part I, The Military Engineer, Vol. 39, November 1947, p. 461.

units. These troops made up about 22 percent of the total troop strength.[44]

On 19 September 1944, while operational planning for the Leyte campaign was still not completed, the army engineer started planning for the Luzon operation. Time was at a premium and a large planning staff was quickly gathered. The army engineer staff with thirty-eight officers and forty-three enlisted men was augmented by a planning group from the 5202d Engineer Construction Brigade.[45] With this large complement engineer planning for the campaign was detailed and precise. Supply planners discovered that some critical items were either aboard ship on the way to the theater or still in the United States. Therefore, the phase-in of supply ships was an important part of planning. Unfortunately, some ships arrived with critical supplies "bottom-loaded"; others had supplies that were needed in two or three locations at the same time. Ports in the United States tried to meet the Sixth Army requirements, but it was a difficult chore for while the Leyte operation was still in progress Mindoro Island was invaded on 15 December 1944. Then, on 9 January 1945 major elements of the army invaded Luzon Island.[46] The shortage of bridging requirements actually delayed the Luzon operation, for the required treadway bridge materials were not in the theater when required.[47]

By April 1945 the engineer staff of Sixth Army had grown to forty-

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[44] Ibid.

[45] U. S., Sixth Army, "Report of the Luzon Campaign," loc. cit., p. 7.

[46] Ibid., p. 22.

[47] Brig. Gen. S. D. Sturgis, Jr., Sixth Army Engineer, "Conference Notes," Hq, Sixth U. S. Army, 5 May 1945, p. 1.

nine officers and sixty-two enlisted men.[48] General Sturgis had separated engineer design work from his planning subsection, convinced that detailed design of important structures must progress concurrently with short-range planning.[49]

The Luzon operation lasted until 30 June 1945. During the last four months one engineer construction group worked directly under the control of the Sixth Army staff.[50] This group spent most of its time repairing roads and bridges.

<u>The Eighth Army Engineer</u>.--On 26 December 1944 the Commander-in-Chief, Southwest Pacific Area directed the Eighth Army to assume control of combat units of Sixth Army that were located in the Leyte-Samar area of the Philippines. The army mission was to destroy the remaining hostile forces and, in addition, to prepare troops for future operations with the Sixth Army.[51]

The engineer work on Leyte was being accomplished by units located in two corps. The army engineer, Col. David M. Dunn, provided the necessary coordination. Engineers improved roads and rebuilt bridges.[52] The shortage of equipment and repair parts plagued the engineers. Likewise, a long rainy season made the engineer tasks seem like endless chores.

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[48]U. S., Forces, Southwest Pacific Area, Sixth Army, Office of the Engineer, "Engineer Section Reorganization and Personnel Requirements," (memorandum to the Chief of Staff, 18 Apr 45), p. 1.

[49]<u>Ibid</u>., p. 3.

[50]U. S., Sixth Army, "Report of the Luzon Campaign. . .," <u>loc. cit</u>., p. 221.

[51]U. S., Forces, Southwest Pacific Area, Eighth Army, "Report of the Commanding General Eighth U. S. Army, on the Leyte-Samar Operation, 26 Dec 44-8 May 45," 1945, p. 2.

[52]<u>Ibid</u>., p. 53.

From early 1945 until hostilities ended on 20 August the Eighth Army Engineer planned and provided support during numerous mop-up operations throughout the Philippines.[53] He provided engineer unit commanders with engineer intelligence, issued construction requirements, and often suggested plans of action.[54]

The Tenth Army Engineer.--In the initial engineer planning for the Ryukyus Campaign, the Tenth Army Engineer, Brig. Gen. George J. Nold, made detailed estimates of engineer requirements to support the tactical forces. In addition, he forecast the base development constructions requirements. Requests for engineer troop units were made upon completion of this two-phased planning task.

Overall, only 70 percent of the requested engineer strength was provided. The shortage of both shipping space and engineer units contributed to the predicament. Consequently, several construction units were placed in support of combat operations and the base development suffered.[55]

Combat engineer support consisted of the construction of beach landing facilities, temporary ports, roads, bridges, demolition work, and airfields.[56] Base development work commenced as soon as possible.

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[53] U. S., Forces, Southwest Pacific Area, Eighth Army, "Report of the Commanding General, Eighth Army, on the Luzon Mop-up Operation," 1946, p. 3.

[54] U. S., Forces, Southwest Pacific Area, Eighth Army, "Report of the Commanding General, Eighth Army, on the Palawan and Zamboanga Operations," 1945, p. 114.

[55] U. S., Forces, Pacific Ocean Areas, Tenth Army, "Report of Operations in the Ryukyus Campaign, 26 Mar 45 to 30 Jun 45," Chap. II, sec. XI, Engineer, 3 Sep 45, p. 2.

[56] Ibid., p. 15.

Supplies were phased onto the island in accordance with the construction program.[57] At the peak of the engineer work approximately 31,000 troops were engaged in some type of engineer work.[58]

The Korean War Functions

The Eighth Army Engineer, 1950-1953.--Engineer troop units were at a premium during the early stages of the Korean War. Those that were available supported the tactical operations. During the first withdrawal action mine fields and demolition work received top priority. In the defense of the Pusan perimeter engineers fought as infantry and prepared extensive fortifications. In the offense and pursuit of the North Koreans the engineers cleared obstacles, restored the roads, and constructed highway and railroad bridges.[59]

Engineer units were still scarce in November 1950 when the Eighth Army executed a pursuit to the Manchurian border. During these hectic days the army engineer had only two construction battalions attached to his headquarters.[60]

The peak engineer work in Korea came in 1951. One engineer combat group was attached to each corps, and three engineer construction groups worked directly for the army engineer.[61] The army troops improved roads,

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[57] Ibid., p. 10.

[58] Ibid.

[59] Paschal N. Strong, "Engineers in Korea-Operation Shoestring," The Military Engineer, vol. 43, Jan-Feb 51 (Colonel Strong was the Eighth Army Engineer in 1950-51), p. 11.

[60] Ibid.

[61] Paschal N. Strong, "Army Engineers in Korea," The Military Engineer, vol. 44, Nov-Dec 52, p. 407.

constructed flood-proof highway bridges and rebuilt railroad bridges.[62]

The army engineer, Col. Paschal N. Strong, conducted extensive advance planning to forecast logistical requirements and prepare construction plans for reopening the lines of communication. He also established the policy for engineer construction. Even before the hostilities were suspended, new-construction for base development was limited by specific dollar values.[63]

In retrospect, the engineer activities in Korea were quite similar to the island-hopping campaigns of World War II. Engineer resources were limited and the employment of troop units was, in priority, first in support of the fighting, and secondly in support of base development. The army engineer, slightly removed from the fighting, maintained an overall perspective of the battle and conducted detailed advance planning to support future operations.

The Eighth Army Engineer, 1964.--By time-frame 1964 the army engineer had reorganized his staff into five sections--an Administrative Office, Construction Division, Operations Division, Program and Budget Division and Real Estate Division.[64] Staff action was geared to the tempo of the Cold War and a good deal of effort was spent on post engineer type activities. However, the Eighth Army Engineer continued to conduct operational planning.

The Operations Division of the engineer staff developed contingency

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[62] Ibid., p. 408.

[63] U. S., Forces, Pacific, Eighth Army, "Engineer Construction," (directive to subordinate units, AG 600.1 KEN-C), 4 December 1952.

[64] Capt. Paul Bazilwich, Jr., Chief, Mapping and Intelligence Branch, Operations Division, Office of the Engineer, Eighth Army, Personal letter to the thesis author, 3 Dec 64.

plans for wartime operations. For example, war plans include detailed instructions for the following types of engineer work:

(1) Construction of floating bridges.

(2) Replacement of railroad bridges destroyed by enemy action.

(3) Airfield repair and expansion.

(4) Pipeline construction.

(5) Over-the-beach operations.

(6) General construction to support advancing elements.

(7) Denial and retardation plans.[65]

Advance planning was based primarily upon resources that were available in Korea. Long-range plans for some time after D+180 included the tentative allocation of resources from outside the theater.[66]

Current Doctrine

Functions

Army doctrine spells out the current functions of the field army engineer. In the theater of operations the field army engineer has retained the combat support functions previously discussed. However, two new functions have been added. First, the army engineer advises the commander in planning and utilizing atomic demolition munitions.[67] Secondly, and most recently added, is a new concept in organization and command--the army engineer will command the army engineer brigade.[68]

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[65]Brig. Gen. Harry G. Woodbury, Jr., Personal letter to the thesis author. (In 1964 General Woodbury returned from Korea where he was the Eighth Army Engineer), 19 November 1944.

[66]Ibid.

[67]U. S., Department of the Army, Engineer Troop Organization and Operations, FM 5-1 (Washington: U. S. Government Printing Office, May 1961), p. 18.

[68]U. S., Department of the Army, Nondivisional Engineer Combat Units, FM 5-142 (Washington: U. S. Government Printing Office, September 1964), p. 7.

The concept of the army engineer brigade is part of a proposed reorganization of units in the field army service area aimed at realigning the doctrine of combat service support. Consequently, the combat service support functions of the field army engineer have been significantly reduced. He no longer controls supply and maintenance units as he did in World War II. Under COSTAR-Combat Service to the Army, a field army support command (FASCOM) will now provide the supply and maintenance services previously furnished by engineer technical service units.[69] [70]

Organization

The revised functions of the army engineer are outlined in Field Manual 5-142, dated September 1964.[71] His brigade headquarters and headquarters company is organized under TOE 5-101E which is still in draft form.[72] However, the brigade concept is doctrine because TOE 5-101 is specifically discussed in Field Manual 5-142. TOE 51-1D, Headquarters, Army, remains the authoritative document for the army engineer section until such time that TOE 51-1E (draft) is published.[73]

The brigade concept establishes a commander and staff to direct and control engineer units in the army service area; and, it provides an

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[69] U. S., Army, Combat Developments Command, Combat Service Support Group, "CO-STAR II (2d Revision)," mimeographed, 17 December 1963, pp. J-1 to J3.

[70] U. S., Army, Combat Developments Command, Combat Service Support Group, "CO-STAR II (2d Revision), Annex L-A, General Support Group (Functionalized)," mimeographed, 29 October 1964, p. L-A-I-9.

[71] U. S., Department of the Army, FM 5-142, op. cit.

[72] U. S., Department of the Army, Headquarters, and Headquarters Company, Engineer Brigade, Army, TOE 5-101E (draft, 1964).

[73] U. S., Department of the Army, Headquarters, Army, TOE 51-1E, (draft, 1964).

additional staff as the army engineer section in the field army headquarters The brigade headquarters and headquarters company consists of thirty-five officers and eighty-one enlisted men. Thirty-seven of these personnel are in the army engineer section.[74]

The organizational concept is outlined below:

(1) Brigade headquarters--it consists of the brigade commander, seven officers and the brigade sergeant major.

(2) Company headquarters--it consists of one officer and fourteen enlisted men to provide command and support services for the headquarters company.

(3) Administration Section--it consists of nine men, under the supervision of the brigade adjutant.

(4) Intelligence Section--this section consists of one officer and five enlisted men under the direction of the brigade intelligence officer.

(5) Operations Section--this section consists of six officers and nine enlisted men under the supervision of the brigade operations officer. The section works very closely with the Army Engineer Section to prepare estimates, plans, and orders for the employment of subordinate engineer units.

(6) Supply and Maintenance Section--it is under the supervision of the brigade supply officer and consists of one officer and nine enlisted men.

(7) Communications Sections--this section consists of thirteen enlisted men under the brigade signal officer. It operates the brigade communications center.

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[74]TOE 5-101E (draft), op. cit.

(8) Aviation Section--this section extends command and control to widely dispersed points. It consists of two officers and four enlisted men.

(9) Army Engineer Section--this section is under the direct supervision of the deputy army engineer. It consists of seventeen officers and twenty enlisted men. The deputy army engineer represents the army engineer at army headquarters. He and the staff assist the army engineer in executing the following staff functions:

(a) Advises the army commander and staff on engineer matters.

(b) Conducts operational planning and coordinates engineer support activities.

(c) Coordinates engineer intelligence and topographic work.

(d) Assists the general staff in the preparation of estimates, plans, and orders.

(e) In conjunction with the army engineer brigade staff, prepares the engineer annexes to army plans.

(f) Provides the staff for the Engineer Element in the Field Army Tactical Operations Center.[75] [76]

Resources

In his capacity as brigade commander, the army engineer will probably have numerous types of engineer units under his command. Exact types and quantities will vary according to requirements and availability. In a three-corps army, possibly the following units would be attached to the army engineer brigade:

(1) Three headquarters and headquarters companies, engineer combat group.

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[75] Ibid. [76] U. S. Department of the Army, FM 5-142, op. cit., pp. 8-9.

(2) Nine engineer combat battalions.

(3) Nine engineer float bridge companies.

(4) Three engineer light equipment companies.

(5) Six engineer panel bridge companies.

(6) Three engineer dump truck companies.[77]

Employment of the combat support units.--Under current doctrine field army engineer units will be employed in much the same way as they supported tactical operations in World War II and Korea. In future wars army engineers will probably expend the majority of their efforts on maintenance of lines of communications, support of river-crossing operations, and barrier and denial operations. These engineers specialize in numerous aspects of engineer combat support supplementing the efforts of the corps engineers. In turn they can expect the close support of Communication Zone engineers.

Summary

The field army engineer should be a man of many talents. Not the least of these is his faculty as a field engineer. He does many jobs and acts in several capacities in his daily contacts with both commanders and staffs. He is many things--a forecastor, estimator, advisor, planner, logistician, organizer, commander, and most of all, a coordinator.

During World War II the army engineer performed his duties under various combat environments. One of his most difficult and time-consuming functions was planning for future operations. Seldom did he have sufficient time to identify and gather all the resources that were needed to accomplish the engineer mission. As a result he did with less than he wanted but usually managed to accomplish his mission through

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[77] Ibid., p. 5.

hard work and ingenuity.

In Korea the army engineer faced an adverse climate, rugged terrain, and an enemy who usually managed to obliterate the lines of communication as he withdrew.

By current doctrine the army engineer is both a commander and a staff officer. In future wars he will be assisted in his work by a functionally organized brigade staff and numerous combat support units. Working together, they will provide an integrated engineer effort in support of the army in the field.

CHAPTER IV

OPERATIONAL PLANNING BY THE FIELD ARMY ENGINEER

General

Engineer planning is a responsibility of engineers at all echelons of command. At the field army level the engineer is concerned with both the current operation and future requirements. His ability to plan effectively and forecast future requirements accurately depends upon his capability to create and control a responsive and productive planning staff.

During wartime operations army engineers develop procedures and organize staffs to facilitate timely planning. Historical files carefully preserve the fruits of detailed wartime planning--the engineer operation plan. However, little has been written which documents the planning methods and techniques that were used to produce the plans.

The remainder of this paper is devoted to a review of planning methods and procedures. In Chapter V a doctrine is developed which suggests a technique to guide the field army engineer in operational planning. Chapter IV prepares the groundwork for the doctrine. Initially, planning theory is considered in some detail because the tools and methods of planning are much better understood when a framework of theory has been established.[1] Subsequently, some well known engineer planning techniques are reviewed and related to operational planning.

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[1]Preston P. Le Breton and Dale A. Henning, Planning Theory (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1961), p. 115.

The Concept of Army Planning

Definitions.--Planning is the act of devising a method for doing something or achieving an objective. Planning is creative in nature; it implies the use of imaginative skill to produce a scheme of future action. It involves a systematic examination of the situation to identify all the factors involved in the proposed operation.

Planning is closely related to forecasting.[2] The planner attempts to predict future actions of people and organizations. He also forecasts future conditions. In light of these factors he drafts sufficient courses of action to satisfy all possible contingencies. Then, each is analyzed in view of forecasted adversities and the desired results. The planner chooses the most feasible course of action as the basis for his concept of the proposed operation.

Planning transforms a rudimentary concept into a plan. It aims to identify what is to be done, where it is to be done, when it is to be done, why it is to be done, who will be responsible for doing it or seeing that it is done, and in broad terms, how it is to be done.

Planning prepares the groundwork for other management functions. During the early planning stage certain concepts and relationships come to light and develop into a framework for organization. Planning is nourished by good coordination between each individual in the planning committee. Directives are drafted, staffed, and upon approval, disseminated in final form. Planning develops the means to control an operation. Normally a plan sets the standards and prescribes reporting procedures. The entire management cycle is defined by the planning function.

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[2] Ibid. p. 8.

The fruits of planning, a plan, must have three basic characteristics. "First, the plan must involve the future. Secondly, it must involve action. Finally, there must be an element of personal or organizational identification or causation."[3] More concisely--a plan is the proposed organization of people and things to perform a future action.

Operational planning is the act of devising an operation plan for a future battle or campaign action. It is conducted in an atmosphere at least slightly removed from the fast tempo of battle. Starting at a high level in a military field command, broad concepts are disseminated to the field army or army group. They visualize and propose an operation. The concepts may outline an operation which will extend over significant time and space.[4] Assumptions may be identified. The planning concept can cover a single operation, or a series to be executed simultaneously or in succession.[5]

At corps and division, staffs are generally so involved in the actual fighting that it is difficult for them to visualize and plan far into the future. However, at field army level the staff is sufficiently removed from the fighting to conduct long-range planning. Consequently, operational planning is habitually accomplished at the field army staff level, and at lower levels intermittently.

Operational planning leads to the development of a plan that may not be executed for several months. The plan is carefully documented. It will

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[3] Ibid., p. 7.

[4] U. S., Army, Corps of Engineers, The Engineer Board, Guide for Engineers of Army and Higher Headquarters, Project No. 8, 23 April 1951, p. 53.

[5] U. S., Department of the Army, Dictionary of United States Army Terms, AR 320-5 (Washington: U. S. Government Printing Office, 28 February 1963), p. 268.

be preceded by detailed and comprehensive estimates and studies. Special staff officers translate the estimates into specific resource requirements. Procurement action can be initiated on the basis of these forecasts.[6]

Operational planning is coordinated by the Assistant Chief of Staff, G3, Operations. However, as regards the field army engineer, this staff officer will coordinate many operational matters also with the Assistant Chief of Staff, G4, Logistics.[7]

Organizing for planning.--As noted in Chapter III, the field army engineer is provided by T. O. and E. with the staffing capability to conduct extensive operational planning. How the staff is organized for work is left to him. Several variations are possible.[8] He may choose to create a permanent subsection to carry out long-range planning while the remainder of the staff concentrates on current operations. For unique operations, a temporary planning group may be created to produce a specific plan. Or, he may take one section and instruct them to conduct both short-range and long-range planning. Realistically, he may choose to use all of these techniques, employing any one at the most appropriate time.

A planning organization involves many people in the field army. These individuals are not all congregated at the army headquarters. Planners are scattered throughout the operational area, and accomplish several

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[6]William A. Carter, Jr., "Employment and Staff Procedures of Engineers With Division, Corps and Army" (unpublished manuscript, 15 March 1946), p. 43. Colonel Carter was the Engineer, U. S. First Army, European Theater of Operations, from May 1944 through October 1945.

[7]U. S., Army, Corps of Engineers, The Engineer Board, "Guide for Engineers of Army and Higher Headquarters," Project No. 8, 23 April 1951, p. 53.

[8]U. S., Army, Command and General Staff College, Staff Organization and Procedures, ST 101-5-1 (Fort Leavenworth: U. S. Army Command and General Staff College, June 1964), p. 79.

planning functions, such as:

(1) Gather data for a plan.

(2) Furnish data.

(3) Analyze and consolidate data.

(4) Conceive ideas.

(5) Prepare draft plans.

(6) Approve plans.[9]

Organizing for work is not simply the preparation of an organization chart. The proper integration of all available planning effort is an exacting subtask of planning.

Communications.--The army engineer needs to devote considerable thought to the problem of communications in planning. Effective communications is a result of the communicator's ability to transmit his thoughts to the communicatee. Multiple means are available for engineers to transmit data within the field army area. Certainly not the least important is person-to-person contact. In developing his planning organization the field army engineer needs to prescribe both oral and written techniques for the effective communication of clear, concise and accurate data.

The Dimensions of a Plan

A plan has a definite beginning and a definite end. It characteristically involves the future, people, and action. Its heart is formed by a course of action chosen as the concept of the operation. But a plan is not necessarily sketchy nor incomplete. On the contrary, it is normally a comprehensive document which visualizes the conduct of an operation from

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[9] Le Breton, op. cit., p. 255.

start to finish. A good plan has several characteristics, these include:[10 11]

Mission orientation.--A plan must outline a concept of operations which directs all effort toward the accomplishment of a specific mission. A plan focuses attention on the prime objective.

Completeness.--A plan must include all the detailed facts. The omission of just one significant aspect can spell failure. Thus, planning is enhanced by the use of check lists and standing procedures. Under stress the human mind might fail to recall pertinent aspects of a planned action. Standard forms and procedures reduce the probability that important considerations are omitted; they also simplify the publication of instructions.

Forecasts contingencies.--A plan must identify all reasonable eventualities and conditions that may bear upon the success of the mission--assumptions, friendly situation, enemy situation, weather, terrain, and all feasible courses of action.

Resourcefulness.--A plan is resourceful. It provides a workable scheme to skillfully employ the available resources--men, machinery, material, equipment, and time. A plan may identify reserve resources to enhance its flexibility.

Continuity.--In a complex plan, particularly, the sequence of milestones must be clearly identified so that the overall plan has one meaningful purpose. All efforts are integrated and work toward that goal.

Prescribes sound organization.--A plan outlines the union of individuals and units to accomplish work. It establishes a clear structure and integration of effort to produce a harmoniously functioning organization. When

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[10] Ibid., p. 23.

[11] U. S., Army, Command and General Staff College, ST 101-5-1, op. cit.,

an existing organization is incorporated into a plan, either the existing organizational structure is accepted as adequate or cogent changes are recommended.

Procedural.--A plan generally prescribes a method for accomplishing the selected course of action. A plan may prescribe the standards of work and set specifications for the quality of the final product. It may expand upon standing operating procedures. In addition, it may provide a time schedule to delimit the work.

Decentralization.--A plan provides for the assignment of functions and tasks which are carefully distributed within the organization. It also provides for the maximum delegation of authority consistent with equitable control.

Provision for control.--A plan provides an adequate system of checks, reports and reviews to assure management that the project will be executed in accordance with the current concept.

Provision for Coordination.--A plan provides for adequate communication between all elements of the organization. It stimulates the interchange of ideas both before and during execution; and, it produces a channel of action for the free interchange of thoughts between leaders. Through adequate coordination leaders are more knowledgeable of the situation, can make more intelligent decisions, and apply resources most effectively.

Flexibility.--A plan must leave room for the modification of the concept when conditions change. Alternate courses of action are usually considered in planning. Flexibility is increased when alternate plans are appended to a basic operation plan.

Quality.--A plan possesses a literary quality that is consistent with the principles of effective military writing. It must be comprehensive yet simple, and concise but clearly written. It also must provide for the logical and accurate presentation of the subject matter.

Economical.--As a general rule, a plan should yield the maximum return for the resources used. In peacetime particularly, the military places significant emphasis upon obtaining the greatest return for each dollar spent. In wartime costs lose some of their significance as tacticians concentrate on the job of defeating the enemy. However, economy of force is a principle that they dare not ignore. In wartime resources of every type may be in limited supply, and conservation of effort will be particularly meaningful.

Authorization.--Legal and competent authority must establish a plan and verify its authenticity.

Classification.--A plan must receive a proper identification to insure proper safeguarding. It is grouped according to its sensitive nature or the scope of defense security information it contains.

Formulating an Operational Planning Procedure

General.--The execution of long-range planning should be preceded by the establishment of an orderly planning procedure. Proper and complete planning results from a systematic and detailed examination of all the factors involved in a proposed operation. The higher the headquarters, the greater is the need for anticipating future action through systematic and habitual planning.[12]

The following planning sequence is taught at the U. S. Army Command and General Staff College:

"(1) Forecast to determine probable commitments.

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[12] Ibid., p. 77.

"(2) Examine probable commitments and establish priority for further preparation.

"(3) Study implication of commitments to determine assumed mission.

"(4) Analyze mission to determine mission tasks.

"(5) Determine guidance.

"(6) Prepare planning studies to develop outline plan.

"(7) Test feasibility of courses of action and select a course of action.

"(8) Prepare complete plans.

"(9) Conduct rehearsals."[13]

A second approach to planning is also taught by the College. It consists of a procedure which phases planning tasks. Phasing is often a sound method for ordering a sequence of planning tasks. Each phase contains a specific aspect of the planning cycle. However, there may be no clear cut time delineation between phases. Some may occur concurrently.[14]

These two approaches have been integrated by the author. The following outline places the doctrinal planning sequence into perspective with the phasing technique:

<u>Phased planning tasks</u>.--

(1) Preliminary phase. Prior to the receipt of a planning directive accomplish the following tasks:

(a) Forecast probable commitments.

(b) Rank probable commitments in priority for further study.

(c) Determine an assumed mission--what must be done and when.

(2) Initial phase. Upon receipt of a planning directive accomplish the following tasks:

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[13] *Ibid.*

[14] *Ibid.*, p. 80.

(a) Analyze the mission and determine the major tasks as well as the prime objective.

(b) Determine planning guidance.

(c) Prepare planning studies and gather data.

(d) Prepare an estimate of the situation and select a course of action.

(e) Recommend a course of action.

(3) Preparation phase. Upon receipt of the commander's decision prepare complete plans. A logical method should be used to determine the tasks, procedures and resources that must be combined to accomplish the mission.[15]

(4) Approval phase. Coordinate to obtain a command review and approval of the plan.

(5) Publication phase. Publish the plan. Make the appropriate dissemination.

(6) Execution phase. Assist subordinate echelons with the completion of their plans and the conduct of rehearsals. Complete all pre-H-hour actions.

It is important that adequate time be allocated to each phase of this planning sequence. Time must be set aside to effect proper coordination at all command echelons. In addition, subordinates at each echelon must have time to react and complete their plans.

Phasing planning tasks provides a comprehensive procedure for developing an operation plan. Planning is not an easy nor automatic process. However, phasing reduces the uncertainty by forcing the planner to integrate time with the total planning task at hand.

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[15] Ibid., p. 79.

Engineer Operational Planning

General.--Engineer operational planning is not governed by a unique set of precepts. It generally follows the sequence described above to answer the questions of what, who, when, where and, at times, why a project is to be accomplished. In addition, because of its analytical nature, engineer operational planning often answers the question of how something will be done.

In the theater of operations, the army engineer prepares advance plans for the allocation of engineer combat and combat support resources.[16] Operational planning is conducted in the field army engineer section, in the engineer brigade and in the engineer group. Progressively more detailed planning is accomplished at lower echelons by the individual who will be responsible to execute a specific project.[17]

The latest army doctrine prescribes that the field army engineer will have a dual role--he not only serves as the field army staff engineer, but also commands all engineer troops attached to the army engineer brigade.[18] But in either role, he is vitally concerned with operational planning in some degree of detail. His planning function can be subdivided into two categories--preliminary engineer planning and detailed engineer planning.

Preliminary engineer planning.--The scope of preliminary engineer planning is quite compatible with the first two steps of the phased planning

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[16] U. S., Department of the Army, Nondivisional Engineer Combat Units, FM 5-142 (Washington: U. S. Government Printing Office, September 1964) p. 9.

[17] U. S., Department of the Army, Engineer Construction and Construction-Support Units, FM 5-162 (Washington: U. S. Government Printing Office, August 1964), p. 13-1.

[18] U. S., Department of the Army, FM 5-142, op. cit., p. 7.

sequence outlined in the preceding section of this chapter.

Preliminary engineer planning requires the continuous forecasting of future requirements.[19] With the aid of guidance from the commander and staff, the field army engineer examines probable commitments and establishes planning priorities. Preliminary estimates are made and pertinent information is passed to the commander and his staff.

Upon receipt of a planning directive the engineer analyzes the mission to identify both its specified and implied tasks. Before proceeding, the engineer seeks to establish the following general data pertaining to the forthcoming operation:[20]

(1) Restatement of the mission.

(2) Location of the project.

(3) Starting and target dates.

(4) Additional resources authorized.

(5) Data pertaining to logistical support.

(6) Established priority or command emphasis.

(7) Control and reporting data.

Continuing his planning sequence, the engineer gathers the following facts which are pertinent to the project:

(1) Theater of operations policies and objectives which may influence his selection of a course of action.

(2) Technical literature.[21]

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[19] Ibid., p. 56.

[20] U. S., Department of the Army, Management; Utilization of Engineer Construction Equipment, TM 5-331 (Washington: U. S. Government Printing Office, November 1962), p. 8.

[21] Ibid.

Concurrently, the engineer directs his intelligence section to make a detailed study of the site of the proposed operation. The following are examples of data that may be accumulated and collated:[22]

(1) Site location terrain studies.

(2) Road and rail net studies.

(3) Data on weather and climatic conditions.

(4) Facts on the availability of local resources.

(5) An estimate of the enemy situation and his probable interference with the proposed operation.

Another study identifies available resources in terms of manpower, equipment and materials.[23] The resource of time is also analyzed to discern its impact on both the planning and execution phases of the operation.

The preliminary part of engineer planning is concluded with the preparation of an estimate of the situation. The estimate ties all the data together and includes the development and analysis of selected courses of action. Appendix C shows a sample format for the engineer estimate of the situation.

Depending on the scope of the project and the headquarters at which it is completed, the engineer estimate may be either detailed or quite broad in nature.

When the commander has approved a course of action, the engineer will immediately direct procurement action for the additional resources that will be required. His attention will be focused on resources that may have to be transported from outside the theater.

Final engineer planning.--The second broad category of engineer planning

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[22] Ibid., p. 5.

[23] Ibid., p. 10.

aims to develop a complete operation plan for the forthcoming project. Initially, broad planning guidance is issued to subordinate engineers. The army engineer staff will develop detailed plans to support a major operation. Centralized planning relieves the corps engineer and the army engineer group commanders of some of the planning burden. Also, centralized planning assures the army engineer of centralized control during execution, and proper coordination of all planning effort.

Final engineer planning consists of six aspects:

(1) Preparation of specifications and designs.

(2) Identification, analysis and ordering of subtasks.

(3) Identification of total resources required.

(4) Scheduling.

(5) Preparation of a reporting and control system.

(6) Completion of the operation plan or project directive.[24] [25]

The field army engineer staff is equipped to prepare plans and specifications for construction projects. In particular, unique structures and structures of particular command interest may be designed at army level. The engineer ultimately responsible for supervision of the project will complete the final design drawings and specifications.

The second and third steps in final engineer planning may present some problems to the army engineer and his planning staff. The identification, analysis and ordering of all the subtasks involved in the proposed operation requires a keen insight of the total job. This visualization of the project from start to finish may be an extremely difficult mental exercise.

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[24]U. S., Department of the Army, TM 5-331, op. cit., p. 10.

[25]U. S., Department of the Army, Post Construction and Rehabilitation, TM 5-360 (Washington: U. S. Government Printing Office, February 1953), p. 120.

Current Army technical and field manuals offer little explicit guidance to aid in identifying all the subtasks that must be accomplished in major combat engineering projects. Guidance is available which identifies the general tasks; however, the method of accomplishing the job is left to either the planner or the project engineer. For example, Army Technical Manual 5-331 outlines twenty-one typical construction tasks that relate to road construction.[26] The job of integrating these tasks into a construction sequence and a schedule is left up to the reader.

Experienced construction engineers may have only minor difficulty in visualizing the job sequence for road construction. Projects that are repeated over and over, and employ essentially the same resources, are simple to plan and schedule. On the contrary, one-time projects, like a major river crossing or port reconstruction, may be very difficult to plan and schedule.

In light of the sketchy doctrine, a theoretical chasm apparently exists in the concept of planning. It occurs in the planning methodology between preparation of the estimate step and preparation of final plans.

The gap is somewhat narrowed by planning doctrine taught at the U. S. Army Command and General Staff College.[27] One planning method suggests starting with the final objective and working backward to develop the required units, organization, combat service support, and other resources that are necessary. The method specifies that the planner visualize the job as he progresses backward, and thereby identify specific tasks, time sequences, conditions, assumptions, and the relative placement of resources. An alternate

[26] U. S., Department of the Army, TM 5-331, op. cit., pp. 23-30.

[27] U. S., Army, Command and General Staff College, ST 101-5-1, op. cit., p. 79.

method is suggested. It starts the planner in the present time-frame and leads him, step by step, through the development of each subtask to reach the final objective.

These planning methods have significant merit yet the planner may be frustrated through his inability to visualize how the subtasks must be integrated to accomplish the mission. Several questions would arise that could defy his ingenuity. The following are representative questions:

(1) What tasks must precede this one?

(2) What tasks cannot start until this one is completed?

(3) Which tasks can be done concurrently?

The planning exercise appears to boil down to the problem of visualizing how the sequence will occur.

A hint of additional help is found in Army Field Manual 5-162.[28] In one short paragraph it suggests that the network analysis system can be used effectively by the commander and his staff to analyze a project before, during and after the operation.[29]

Subsequently, the planner completes his identification of what must be done. His next step is to identify the total resources needed for the project. The task of estimating the requirements for men, materials, and equipment involves the preparation of the following summary sheets:[30]

(1) Quantity surveys which list each subtask in terms of what work must be accomplished. The work descriptions are based upon intelligence

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[28]U. S., Department of the Army, FM 5-162, op. cit., p. 13-8.

[29]This single statement in the field manual scarcely does justice to the network analysis system. Although it is a relatively new technique, the network analysis system has many broad applications in the military.

[30]U. S., Department of the Army, FM 5-162, op. cit., p. 13-3.

studies, field surveys and designs.

(2) Work estimate sheets which summarize the resources required to accomplish each subtask.

(3) Equipment requirement schedules which list each of the major pieces of equipment and summarize the dates it is required for each subtask.

(4) Labor requirement schedules which identify each category of manpower and units required for each subtask. The sheets list who will do each task and when the manpower is required during project execution.

(5) Material requirement schedules which list, by subtask, all the materials required. This summary provides both quantitative and qualitative requirements for each day of the project.

These summary sheets take their final form as the project schedule is developed in graphical form. The schedule is the product of the plan of execution that the planner has devised either in his mind or, preferably, on paper. The planner arranges each subtask in the logical sequence that he visualizes it will occur. He balances the available resources so as to accomplish the total task in the least amount of time.[31] The arrangement of task sequences will often be limited by the availability of critical items of equipment or certain job skills.

In construction scheduling two principles guide the planner:[32]

(1) As soon as possible, start the job that will take the longest to complete.

(2) Keep resources on one job as long as possible; avoid moving men and equipment back and forth between subtasks.

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[31] U. S., Department of the Army, TM 5-331, _op. cit._, p. 12.

[32] _Ibid._

Figure 2, Chapter 1, depicts a sample construction operations schedule and progress chart.[33]

Regardless of how much detail is built into a schedule it must be laid out in some presentable format so as to assure the planner that he will meet the project target date.

The procedure just described is particularly applicable in planning a construction project. Admittedly, the sequence is quite detailed. At the other end of the planning spectrum there will be times when planning is rather general in nature. Sometimes the field army engineer will complete his planning simply by visualizing the subtasks required and then assigning combat support and construction missions to his engineer combat groups, or the corps engineers, and tailoring their organizations by attaching or detaching combat battalions and separate companies.[34]

The next step in final engineer planning is the preparation of a system of reports to aid in controlling project execution. Progress reports assure the engineer of the following facts:[35]

(1) All units are working together toward the primary objective.

(2) Commanders are making the intelligent use of resources, priorities and delegated authority.

(3) The engineer staffs are properly coordinated and integrated to support the decisions and requirements at all levels.

(4) The project is proceeding according to schedule.

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[33] *Ibid.*, p. 15.

[34] U. S., Department of the Army, *Field Service Regulations, Larger Units*, FM 100-15 (Washington: U. S. Government Printing Office, December 1963), p. 28.

[35] U. S., Government, PERT Coordinating Group, *PERT Guide for Management Use* (Washington: U. S. Government Printing Office, June 1963), p. 31.

Progress reports measure performance against the standards that were set in the engineer plan and the operations schedule. The system of reports should be only so detailed so as to give the army engineer an adequate picture of the field activity. An excessive amount of daily progress reporting will only hinder the field commanders in accomplishing their jobs.

The plan for reporting project status might include the following reports:

(1) Spot reports which are made by electronic means, or in person.

(2) Daily production reports which list progress made on each major subtask.

(3) Cumulative production reports which show the total accomplishments on each major subtask from the start of the project to date.[36]

Standing operating procedures can be used effectively by the engineer in planning project controls. A uniform procedure can often be established for reporting many construction projects. In addition, construction policies and standards can be disseminated as standing procedures.

A plan for personal inspections might be outlined during this phase. Staff inspections supplement personal inspections by the field army engineer.

Together, control measures set the standards, aid the engineer in measuring progress, and provide adequate facts for him to make intelligent and timely decisions. They permit the army engineer to manage by exception. Consequently, the routine work progresses under the supervision of subordinate leaders. However, when actual progress differs significantly from the plans and schedules, the army engineer can step in and redirect the activities so as to best accomplish the mission.

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[36] U. S., Department of the Army, TM 5-331, op. cit., pp. 19-20.

The final step in engineer planning produces and disseminates the engineer operation plan.

The field army engineer prepares the engineer annex to the field army operations order.[37] A standard format is used--The Standard NATO Agreement Number 2014, Operations Order-2d Edition.[38]

The engineer annex specifies engineer missions for the army engineer brigade commander and each corps commander. Instructions are in sufficient detail to insure that each mission is completely understood. The engineer annex may include an engineer operation overlay to graphically portray a portion of the instructions.

Orders to the army engineer brigade commander include instructions to each combat engineer group. However, the brigade commander may issue separate instructions to the groups and separate battalions and companies attached to his brigade.

A job directive is normally issued by the brigade to an engineer combat group for construction projects. This directive is often quite general in nature, providing the group commander significant flexibility in planning the exact method of execution. The directive authorizes the commander to requisition specific materials and equipment if it is so stated. Preliminary or fragmentary specifications, plans and bills of material may accompany the directive.[39] Also, it may refer to standard specifications and drawings contained in Technical Manuals 5-301, 302 and 303, The Engineer Functional Components System. The overall directive may

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[37] U. S., Department of the Army, FM 5-142, op. cit., p. 9.

[38] U. S., Army, Command and General Staff College, ST 101-5-1, op. cit., p. 257.

[39] U. S., Department of the Army, TM 5-331, op. cit., p. 8.

instruct a subordinate commander to present his plan for approval.[40]

Summary

The field army engineer plans and supervises the engineer resources assigned to the field army commander. He and his staff conduct detailed operational planning while engaged in day-to-day battlefield operations. However, this staff is sufficiently removed from the fighting to conduct long-range planning.

Army planning follows a general sequence of six phases. These phases and the scope of each are briefly summarized in Table 6. Note in this table that the procedure for engineer operational planning closely parallels the format for Army planning.

Doctrinally, the Army sequence of planning fails to provide detailed guidance to assist a planner in developing a method for planning project execution. A gap in doctrine seems to exist between the procedure established for deciding upon a course of action, and the next step where complete plans are prepared.

Engineer field manuals provide some guidance to planners to help them visualize how a project will be completed. In general, they identify the major tasks to be accomplished in common projects; however, the job of integrating these tasks into a construction sequence and schedule is left up to the planner. Consequently, a planner, if he is inexperienced in the mission to be performed, may find difficulty in attempting to visualize how a multitude of subtasks are to be integrated in order to best accomplish the assigned mission.

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[40] U. S., Department of the Army, FM 5-162, op. cit., p. 13-1.

TABLE 6

COMPARISON OF SEQUENCES FOR ARMY PLANNING

General Sequence of Planning Army	Engineer Operational Planning
1. Preliminary Phase. a. Forecast commitments. b. Rank commitments. c. Assume mission. 2. Initial Phase. a. Analyze mission. b. Obtain guidance. c. Gather data. d. Prepare estimate. e. Recommend. 3. Preparation Phase. Prepare complete plans. 4. Approval Phase. Obtain approval of plans. 5. Publication Phase. Publish plans. 6. Execution Phase. Assist subordinates to rehearse.	1. Preliminary Engineer Planning. a. Forecast future requirements. b. Establish planning priorities. c. Make preliminary estimates and render information. d. Analyze actual mission. e. Establish facts. f. Gather data. g. Prepare estimate. h. Recommend. 2. Final Engineer Planning. a. Prepare designs. b. Identify subtasks. c. Identify resources. d. Schedule. e. Plan controls. f. Complete the engineer plan.

CHAPTER V

A PROPOSED DOCTRINE FOR THE APPLICATION OF THE NETWORK ANALYSIS SYSTEM IN OPERATIONAL PLANNING BY THE FIELD ARMY ENGINEER

This chapter proffers a doctrine for the application of the network analysis system in operational planning by the field army engineer. The following doctrine is based upon the field army engineer's requirements to accomplish operational planning. Furthermore, the technique proposed is generally compatible with the theory of the network analysis system discussed earlier. The doctrine combines some features of both PERT and CPM and tailors the resulting theory to conform with the environment of a theater of operations.

The Need For A Planning Technique

Lessons from history.--In World War II and in Korea the army engineer learned to accept the fact that there was seldom sufficient engineer resources available to satisfy all his requirements. Because of this general limitation, each campaign was planned in as much detail as time and experience accommodated.

As a rule, most historical reports do not give the reader a keen insight as to how planning staffs were organized, guided or how they actually conducted operational planning. However, the reports do outline a pattern of the army engineer's planning requirements. Generally, the field army engineer maintained a permanent planning staff actively engaged in planning for future operations. Men with the most experience in field engineering operations and logistics were chosen to supervise the planning staffs. Unfortunately, combat attrition and the need to expand the Army caused a constant drain on the staffs. Versatile and experienced planners were not always available.

Time was often a limiting factor in operational planning, primarily because of the long lead-time required to obtain materiel from outside the theater. The sheer magnitude of more complex plans required the careful integration of many types of resources; planning was a time consuming task in itself.

None of the theaters had an endless supply of engineer units, nor materiel. Priorities were established in many operations to carefully regulate the employment of available engineer resources.

What an engineer plan should provide.--The engineer plan for a future operation should provide a clear and concise picture of the proposed operation. Principally, the plan should show the objectives of the operation, an outline of a concept of the operation, a list of tasks to be accomplished, a task organization to execute the mission, the resources to be employed, a schedule for the proposed work, and in some instances a method for executing the plan. The plan also needs to provide a means for effective communications, coordination of effort, and the proper control of resources.

How the army engineer plans.--The general sequence of Army planning, as outlined in Chapter IV, provides a sound planning doctrine upon which the army engineer can organize his own planning procedure. The phased sequence of planning is a logical approach to the total planning requirement. In the preliminary phase the engineer forecasts and ranks his future commitments and provides initial planning guidance to his subordinates. Timely estimates may show a need for critical materials and stimulate logistical actions. During the initial phase of planning the engineer analyzes his mission, obtains facts and guidance, and then prepares a detailed estimate of the situation in order to select the most feasible course of action for accomplishing his mission. In the preparation phase of planning final engineer designs, methodology and schedules are produced. Then, upon approval, plans are published and pre-H-hour activity is completed.

Obstacles to planning.--As discussed in Chapter IV, the doctrine of Army planning offers limited assistance to the army engineer in his endeavor to visualize a future operation from start to completion. This aspect of planning can be a critical problem, particularly on projects where many tasks must be accomplished concurrently. Explicit doctrine does not exist to assist a planner in visualizing how a job will be done. Consequently, though a plan is sound in its concept this is no assurance that it will be both properly documented and scheduled. It is quite possible that a planning staff could overlook pertinent facts, be unaware of certain interdependencies among the tasks, or fail to correctly visualize the sequence of the operation. The danger here is that if available resources are not productively alloted some tasks will drag for lack of resources while elsewhere idle resources go undetected.

In addition, incomplete planning could result in the preparation of haphazard time estimates and ineffective schedules. Poor visualization of a plan of execution can lead to a needless waste of resources. When a staff fails to fathom the intricacies of an operation, or is pressed for time, a simple planning technique might be the one ingredient needed to foster timely and effective planning.

The Doctrine

General.--The network analysis system is a set of procedures and techniques for the effective planning of objective-oriented work. It is a concept which conditions the planner's thought processes and forces him to analyze the proposed work in considerable depth.

The field army engineer can use this management tool beneficially to assist himself in creating detailed plans and schedules for a future operation. The system enables him to graphically portray conventional planning in such detail as is required to adequately visualize the proposed action.

The networking technique augments but does not replace the general sequence for Army planning. Specifically, it provides guidance to the engineer in formulating detailed methodology, in planning resource and time requirements, and in scheduling the proposed operation.

Definitions.--

Prime objective--The most important aspect of an assigned mission; that goal toward which all planning is directed; usually the end result of a project. Example: In a river-crossing operation, the prime objective could be to transport the tactical unit across the water gap quickly and safely.

Supporting objectives--A groupment of the major tasks to be completed in order to attain the prime objective. Example: In constructing a bridge, the supporting objectives could be completion of the piers, completion of abutments, completion of the superstructure, and completion of the approach roads.

Work packages--The categories of work required to attain a supporting objective; the skills or specialities of a work force. Example: In constructing a bridge pier, the work packages could be the excavation, form work, concrete work and inspection processes.

Resources--The men, units, equipment and materials that can be made available at any time to accomplish work. Example: An engineer float bridge company with its authorized equipment.

Network model--A two-dimensional plan of the steps and sequences to be followed in achieving the prime objective of a project. The model consists of events, activities, relationships, resource allocations, and time estimates. Figure 9 shows a sample network.

Event--A specified accomplishment in a plan; a milestone; a clearly identifiable point in time to mark the start or completion of a specific task.

Key event--A key milestone; one of possibly several events chosen by a planner for careful scrutiny during project execution; a major accomplishment in the planned work. An event, or key event, is represented on a network by a circle.

Activity--The clearly definable work required between two events; a task to be accomplished, to which a particular quantity of resources will be applied; the most detailed subdivision of work packages made by a planner in visualizing the operation. Proper identification of all the activities is the most important aspect of the network analysis system. An activity is represented on a network by an arrow.

Relationships--The sum total of the affiliations, connections and dependencies that exist between activities and events.

Latest allowable completion time (T_L)--The latest allowable calendar time that an activity can be completed without delaying the completion of the project. The T_L value is calculated by subtracting the sum of the estimated times for the activities on the longest path between the given activity and the end event of the project from the latest allowable time for the end event.

Earliest expected completion time (T_E)--The earliest calendar time that an activity can be expected to be completed. The T_E value is equal to the sum of the estimated times for the activities on the longest path from the beginning of the project to and including the given activity.

Critical path--The longest time-path of interconnected activities in a network diagram; that time-path in a network which determines the duration of the planned work.

Slack time--The difference between the latest allowable completion time and the earliest expected completion time for a given activity in a network. Slack exists in each time-path of a network except the critical path. Slack represents idle resource; its magnitude represents the degree of scheduling flexibility that exists for the activity with which it is associated.

Procedure.--The sequence outlined below establishes a procedure for the execution of operational planning by the field army engineer. The following six phases of planning integrate the network analysis system with the general sequence of Army planning:

(1) Preliminary phase of planning.--Prior to the receipt of a planning directive, periodically forecast future tactical requirements based upon logical assumptions or knowledge of tentative plans of higher headquarters. Next, analyze these requirements and determine probable engineer commitments. Rank these probable commitments in a priority for further study.

Draft planning assumptions for each probable commitment and make a preliminary engineer estimate of the situation. Execute that logistical action required to preposition forecasted materiel requirements. Provide continuous guidance and information to the commander, his staff and to subordinate engineer commanders.

(2) Initial phase of planning.--Upon receipt of a planning directive commence this phase of planning. Analyze the mission and identify the prime and tentative supporting objectives.

Seek planning guidance from the commander and resolve a final list of supporting objectives. Review the specified and implied engineer tasks and insure that each is represented by at least one supporting objective. These supporting objectives outline the scope of the work. Rank the major tasks in their probable order of execution. Note those tasks which can be completed concurrently. In addition, identify the dependencies that exist between the tasks.

Identify the work packages that will be associated with each major task, and hence must be completed to achieve each supporting objective. Identify the engineer units and special equipment that may be needed in each work package.

Prepare planning studies to obtain intelligence about the terrain, and enemy as appropriate. In addition, gather data on time restraints, material and equipment limitations, personnel shortages, weather forecasts, and any other difficulties which are inherent in the general situation.

With a knowledge of work package requirements, develop a list of those units, special equipment and materials that can be made available for the operation. Consider all possible sources. Also, identify the availability of prisoners of war, indigenous personnel, and military labor pools.

Prepare an engineer estimate of the situation in accordance with Appendix C, and decide upon the most suitable course of action that will accomplish the prime objective. Recommend this course of action to the commander and his staff. Modify the course of action as required by the commander's decision. Translate this decision into a concept for employment of available resources to achieve the prime and supporting objectives.

Provide subordinate engineer commanders, and the corps engineers as applicable, with the preliminary planning guidance required for them to initiate concurrent planning. As a minimum, provide each commander with information on the concept of the operation, an estimate of additional resources that may be made available to them, the enemy situation, weather and terrain, and time limitations that have been placed on the planning. Indicate whether or not their plans are to be submitted for approval. From this point until planning has been completed stimulate continuous coordination between engineer planners at all levels.

(3) Preparation phase of planning.--Prepare a network model for the overall project in accordance with the mechanics of network construction outlined in Appendix A. In choosing the activities that are to be placed in the network, visualize those tasks that can be completed by the combined efforts of engineer combat battalions, separate engineer companies and special engineer detachments. Therefore, do not be biased in planning by the present organization of each assigned engineer combat group. Tailor the engineer groups as necessary to accomplish the overall mission.

When the network is drafted, apply those resources which are required to complete each activity in an equitable way. At this point be concerned with the apportionment of type units rather than the preparation of a task organization.

Next, prepare one time estimate of the duration of each activity, and apply them to the diagram. At the discretion of the planner, three time estimates may be made for each activity in accordance with Appendix B; in this technique an expected time is then calculated for each activity and placed on the model.

At this point in the planning the network model consists of arrows representing activities, circles representing events, several time-paths of interconnected activities, and a notation of the resources and time required to complete each activity. A sample network is shown in Figure 9.

Study the network and compute a time-length for each path. Identify the critical path with a heavy line. Calculate the expected project completion time. Tabulate the pertinent network data as shown in Table 7.

Redraw the network by orienting it to a horizontal time scale. Express this scale in terms of hours, days or weeks depending upon the scope of the work. Draw each activity parallel to the horizontal axis, if possible. Start each activity at the earliest time thereby placing all slack time initially in the later stages of the project.

Prepare a unit-loading table and append it to the time-scaled network. A sample table and network is shown in Figure 10.

Evaluate the network in light of the following aspects:

(a) The expected project duration.

(b) The critical path and each activity on this path.

(c) The most time consuming activities.

(d) Potential problem areas that may occur during execution.

(e) Location of slack time and the leeway which is available for scheduling most activities.

(f) Identification of key milestones.

(g) The unit-loading requirements.

Consider modifying the network, if possible, to provide a less costly or a less time consuming plan. First, if the critical path establishes an undesirably lengthy project time, trade-off excess resources from slack paths to shorten the critical path. Secondly, take advantage of the slack time available on various paths and distribute some activities more evenly throughout the project. In this manner some reduction can be made in both resource and possibly time requirements. A sample adjusted time-scaled network is shown in Figure 11.

Use the network model to schedule the operation; see Figure 2, Chapter I. Group work packages with their associated tasks on a bar-graph type schedule. Check subordinate plans with the proposed schedule and make necessary adjustments so as to provide a harmonious execution effort.

Plan control measures that will be used during project execution. The key milestones previously identified can provide a useful tool for checking on progress. Establish a system of recurring reports which will compare scheduled milestone times versus actual or latest forecasted times. In addition, plan to update the bar-graph schedule and network model periodically to reflect project status.

Utilize the network model, schedule, and control plan to prepare the final engineer plan for the operation. Draft the engineer annex to the army operations order, plus those supplemental directives which are necessary to guide the army engineer brigade units.

(4) Approval phase of planning.--Coordinate with the general staff and obtain a command review and approval of the plan.

(5) Publication phase of planning.--Publish and issue the engineer plan. Appropriate annexes should include both a schedule and a copy of the network model to depict the concept of the execution.

(6) Execution phase of planning.--Assist subordinate commanders in completing their plans. Encourage their use of the network analysis system. Complete all pre-H-hour planning requirements and logistical actions.

Sample Application of the Doctrine

A hypothetical planning problem is presented in this section to demonstrate the mechanics of the proposed doctrine. The example represents a considerably more simplified situation than what might be expected in an actual theater of operations. No attempt has been made to simulate the often trying conditions of battle. Likewise, only a few engineering tasks are discussed. In an actual situation the army engineer would probably be confronted with a much more complex planning requirement. His planning work would likely be made more complicated by changes in work priorities, fluctuating amounts of resource, and disruptions caused by enemy action and acts of God. The following illustration is purposely uncomplicated in order to highlight the basic techniques and salient aspects of the proposed planning doctrine.

The sketch map shown in Figure 8 depicts a sample planning problem in which the field army is supporting two corps in the advance. The roads drawn on the map have previously been used by the corps as main supply routes. However, due to adverse weather, enemy action and heavy traffic the roads and bridges are in poor condition.

In this problem the army engineer is required to plan and schedule the total army engineer brigade support that will be provided during the next forty-five days. The G3 has forecast that the present boundaries will be displaced forward at the end of this period.

Analyzing the situation, the army engineer identifies his prime objective for the next forty-five days as that of providing general support to the army throughout the service area. Five engineer float bridge companies have been attached to the corps. No other army engineer brigade units are forecast for commitment in the corps areas.

Analyzing his prime objective, the army engineer identifies two supporting objectives and their associated work packages; they are:

(1) Objective 1: Maintain the Army Road Net.

Work packages:

(a) Rehabilitate existing roads.

(b) Widen existing roads.

(c) Rehabilitate existing bridges.

(d) Construct additional floating bridges.

(e) Construct additional fixed bridges.

(2) Objective 2: Provide general support to units in the service area.

Work package: Construct temporary frame structures.

The army engineer follows the proposed planning doctrine and develops a systematic study of the work to be accomplished. He proceeds in planning from a general analysis to a specific identification of his future commitments. The work packages he identified establish the types of engineer operations and special skills that will be required to achieve

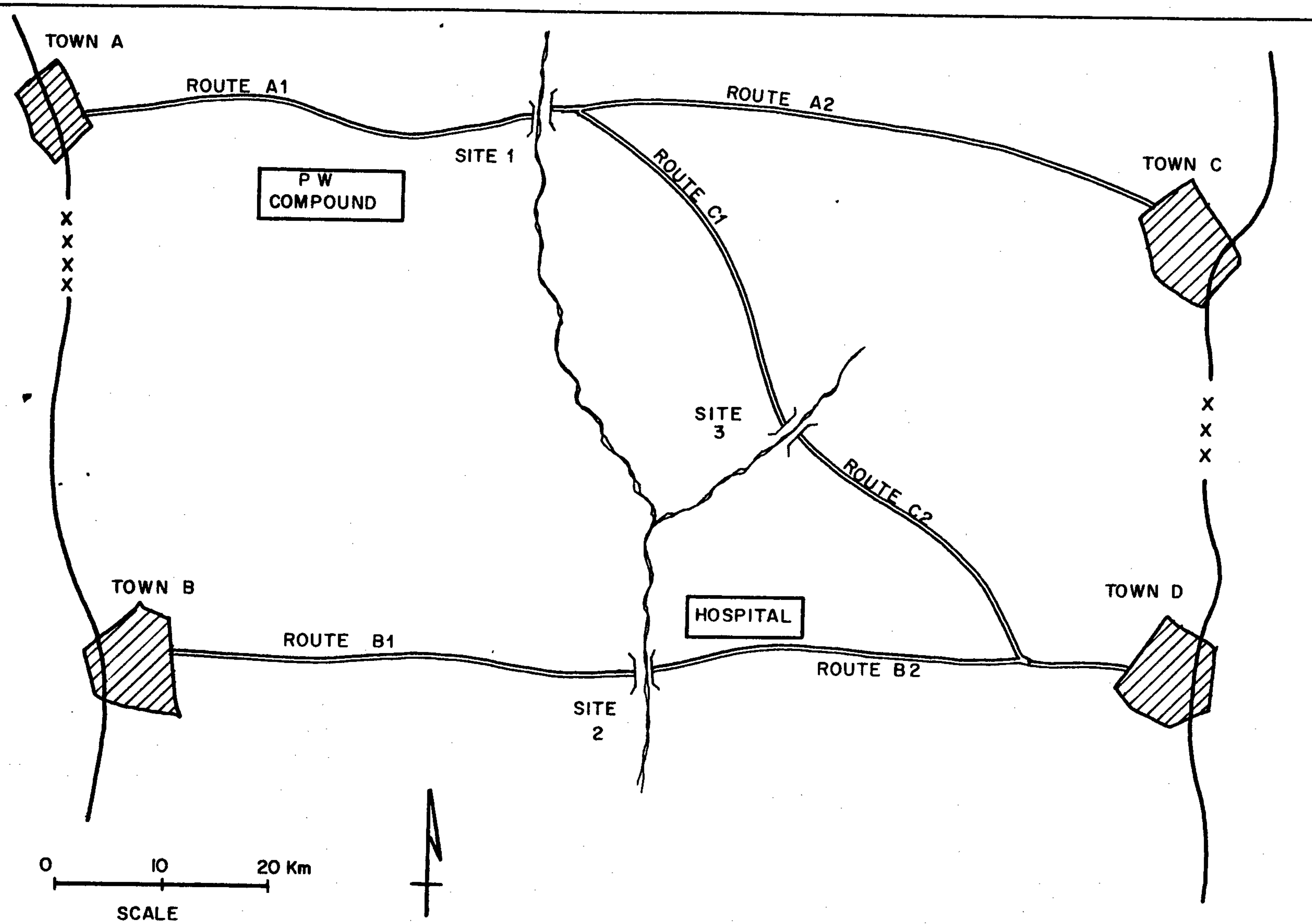


FIG. 8--Sketch map of Army Road net (Hypothetical Situation)

each supporting objective.

Next, he directs his staff to prepare studies and to obtain intelligence about the existing road net, terrain and drainage systems in the area. Engineer reconnaissance reports are studied. Unit requests for general construction are reviewed.

A list of resources is prepared to identify the major engineer units and materials that will be available for this work. These resources are available:

(1) Nine engineer combat battalions (abbreviated on Table 7 as B).

(2) Four engineer float bridge companies, with their bridges (FB).

(3) Four engineer light equipment companies (LE).

(4) Five engineer dump truck companies (DT).

(5) Three engineer panel bridge companies, with their bridges (PB).

(6) Lumber, locally available in extensive forest stands.

(7) Road ballast and fill, to be obtained from any of several pits and quarries in the area.

Coordinating with other members of the staff, the army engineer prepares a list of the specific tasks that have to be accomplished during the subsequent forty-five days. This time period is meaningful to planning because the G3 has previously forecasted that the corps rear boundary would probably be displaced forward by that time. The tasks are shown in Table 7, with an estimate of the unit resources and time required to complete each project.

Next, the engineer prepares a network model to represent the sequence in which his work will be accomplished. This diagram is shown in Figure 9. It depicts the total army engineer combat service support mission. Had they been required, it might have included such other projects as construction of air-landing facilities, pipelines, railroads and port rehabilitation.

As the network takes shape several planning factors are identified by the engineer. In his best judgment these conditions restrict the manner in which the work can be executed:

(1) Routes A and B, though passable, require extensive repair; therefore, effort will be spent in rehabilitating each section of road before proceeding with work to widen that section.

(2) Route C1, barely passable, will be rehabilitated as soon as the rehabilitation of Route A1 is completed. Route C2 is in fair condition and will not be improved until the rehabilitation of Route C1 is completed. Finally, Route C widening will begin once the initial repair is completed for a particular section.

(3) When Route C1 is rehabilitated the panel bridge at Site 3 will then be constructed.

(4) At each river-crossing site the existing bridge will be rehabilitated before starting the construction of a second floating bridge; also, the second floating bridge will be completed before starting work on a semi-permanent bridge.

(5) The construction of the hospital and PW compound each must be completed within thirty days.

(6) Work on the projects will generally proceed from west to east.

The above limitations are imposed in this hypothetical problem to illustrate some of the planning restrictions that could possibly face the engineer in the theater of operations.

Using the mechanics of network construction prescribed in Appendix A, the engineer develops a diagram that depicts an exact sequence of

TABLE 7

TABULATION OF NETWORK DATA, ARMY
ENGINEER COMBAT SERVICE SUPPORT

Task	Symbol	Description	Unit Resource[a]	Time Est[b]	T_L[b]	T_E[b]	S[b]
1-2	FB1	Rehab. Float Br, Site 1	B, FB	3	15	3	12
2-3	FB12	Cons. Second Float Br, Site 1	B, 2FB	5	34	8	26
3-4	TP1	Cons. Trestle Pile Br, Site 1	2B, LE	11	45	19	26
4-5	D	Dummy					
1-6	FB2	Rehab. Float Br, Site 2	B, FB	2	18	2	16
6-7	FB22	Cons. Float Br, Site 2	B, FB	3	36	5	31
7-8	TP2	Cons. Trestle Pile Br, Site 2	2B, LE	9	45	14	31
8-5	D	Dummy					
1-9	B1	Rehab. Road B1	2B, LE, DT	8	18	8	10
9-11	B2	Rehab. Road B2	2B, LE, DT	12	30	20	10
6-9	D	Dummy					
9-10	B12	Widen Road B1	2B, LE, DT	9	30	17	13
10-11	D	Dummy					
1-18	HC	Construction of Temp. Hospital	3B, LE, DT	3	3	30	27
18-5	D	Dummy					
1-19	PW	Cons. PW Compound	B	15	15	30	15

TABLE 7--Continued

Task	Symbol	Description	Unit Resource[a]	Time Est [b]	T_L[b]	T_E[b]	S[b]
19-5	D	Dummy					
11-5	B22	Widen Road B2	3B, LE, DT	15	45	35	10
1-12	A1	Rehab. Road A1	2B, LE, DT	15	15	15	0
2-12	D	Dummy					
12-14	A2	Rehab. Road A2	2B, LE, DT	17	32	32	0
12-13	A12	Widen Road A1	B, LE, 2DT	15	32	30	2
13-14	D	Dummy					
14-5	A22	Widen Road A2	3B, LE, 2DT	13	45	45	0
12-15	C1	Rehab. Road C1	2B, LE, DT	6	23	21	2
15-16	PB3	Rehab. Panel Br, Site 3	B PB	4	38	25	13
16-5	DTT3	Cons. 2-Lane Timber Br, Site 3	B	7	45	32	13
15-17	C2	Rehab. Road C2	2B, LE, DT	8	31	29	2
15-5	C12	Widen Road C1	2B, LE, DT	10	45	31	14
17-5	C22	Widen Road C2	B, LE, DT	14	45	43	2

a Key: B - Engr Combat Bn.
LE - Engr Light Equipment Co.
DT - Engr Dump Truck Co.
PB - Engr Panel Bridge Co.
FB - Engr Float Bridge Co.

b Days

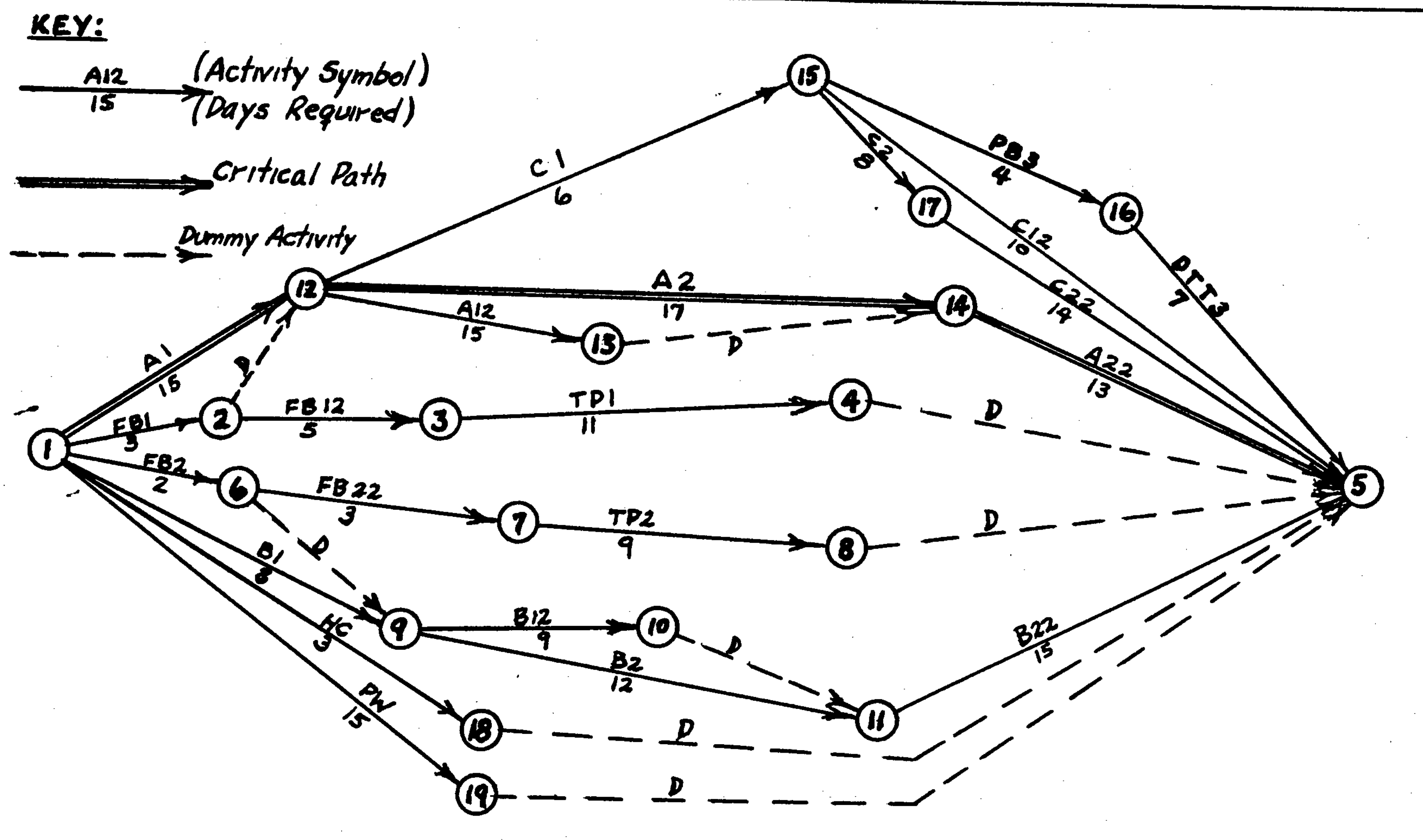


Fig. 9.-- Network model. Army engineer combat service support.

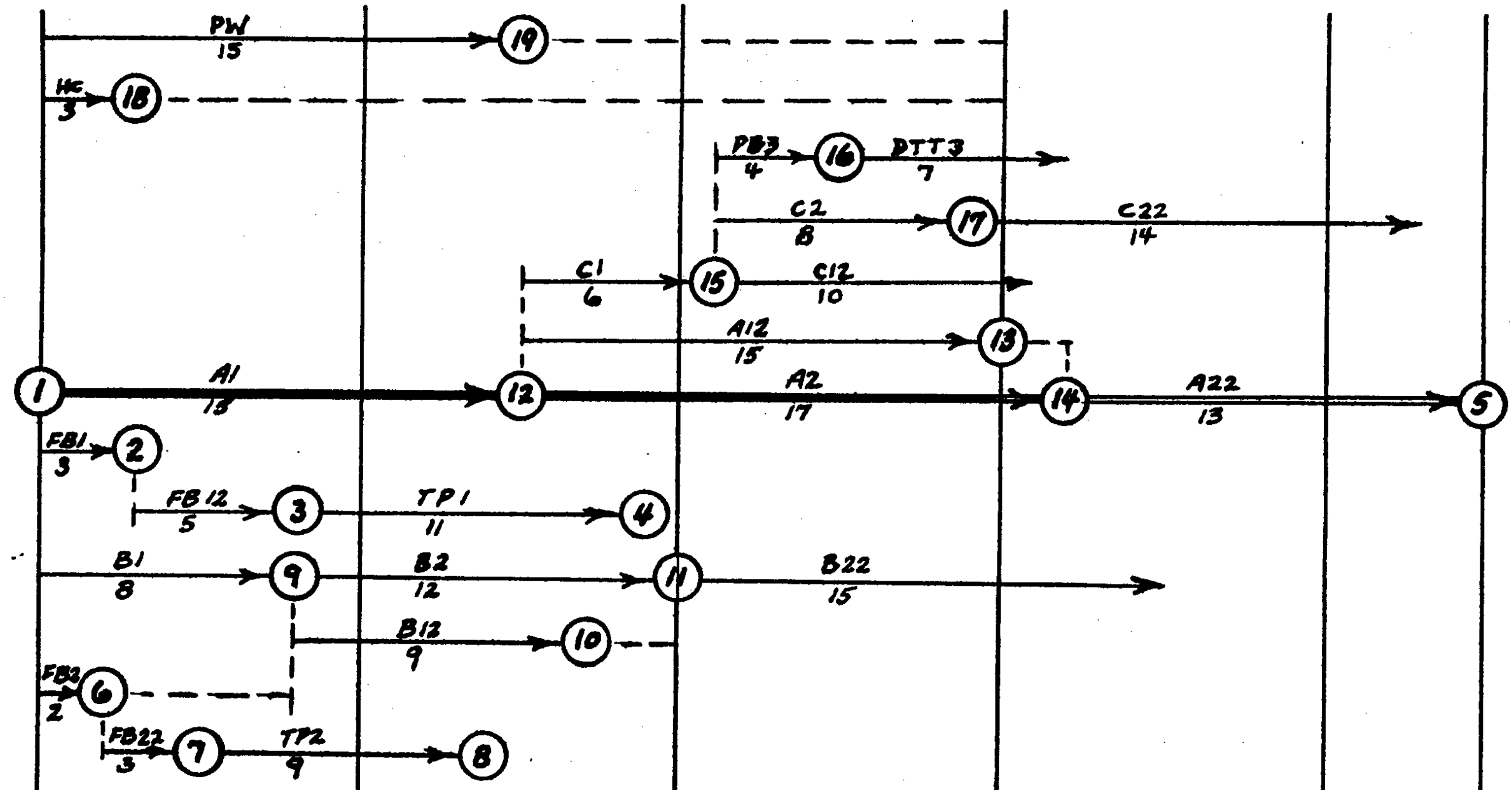
operations. The network reflects the precise order in which he wants the tasks to be accomplished.

In Figure 9, each numbered event is a specific point in time when one or more activities will end, can begin, or both. For example, event 6 signifies the completion of the rehabilitation of the floating bridge (FB2) at Site 2. In accordance with the engineer's guidance, this event must take place before construction can start on the second floating bridge (FB22). In addition, dummy activity 6-9 indicates that event 6 has to occur before event 9 occurs. Event 9 signifies the start of repairs on Route B2; it cannot occur before activity B1 is completed.

A time-length is computed for each path in the network diagram. The expected project duration is forty-five days. This is established by the length of the critical path--events 1, 12, 14, and 5. Slack time is next computed and is shown in Table 7.

In Figure 10 the network model is redrawn and oriented to a horizontal time-scale. Each activity is planned to start as early as possible. A unit-loading table is also shown in Figure 10. Studying this diagram the engineer notes that the plan requires more unit resources than are available. He also sees that there is not an even distribution of work throughout the time period.

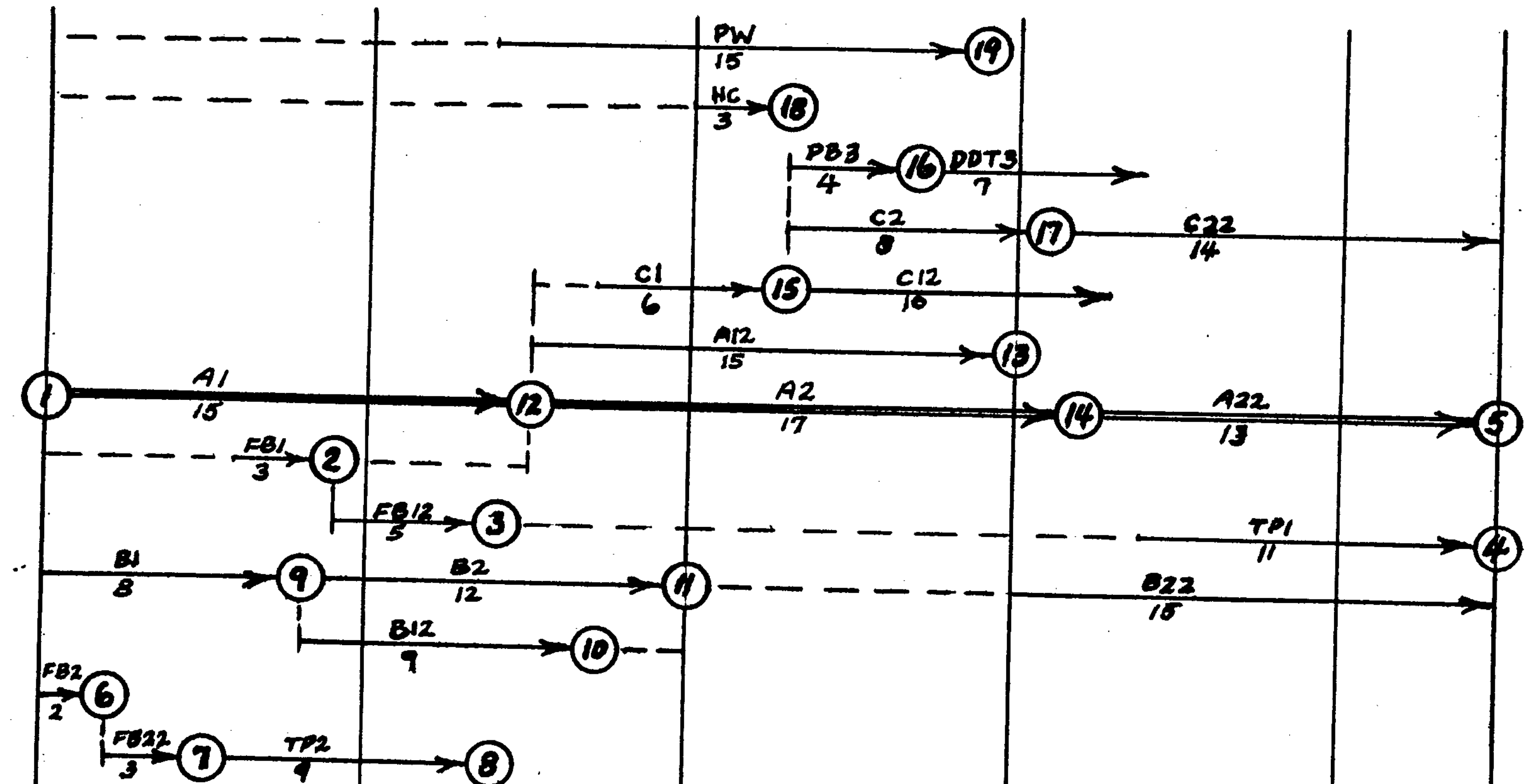
Not satisfied with his preliminary schedule of work, the engineer next revises the time-scaled network, as shown in Figure 11, to more evenly distribute the workload over the duration of the project. The unit-loading diagram now indicates that the tasks are well distributed throughout the project, and all units are productively employed. The work can be completed with the available resources. In addition, barring unforeseen delays, all known work will be completed within the prescribed



B	7	8	8	10	11	11	10	7	4
LE	2	2	2	5	6	5	5	3	2
DT	2	2	2	3	6	6	6	4	3
PB	-	-	-	-	-	1	-	-	-
FB	2	3	2	-	-	-	-	-	-

0 5 10 15 20 25 30 35 40 45 Days

Fig. 10.--Preliminary time-scaled network and unit loading table. Army engineer combat svc. support.



B	5	5	6	7	9	9	8	9	9	9	9	9	9	9
LE	2	2	3	3	4	4	3	4	4	4	4	4	4	4
DT	2	2	2	2	3	3	3	5	5	5	5	4	4	4
PB	–	–	–	–	–	–	–	–	–	1	–	–	–	–
FB	1	1	–	1	1	2	–	–	–	–	–	–	–	–

0 5 10 15 20 25 30 35 40 45 Days

Fig. 11.-- Final time-scaled network and unit loading table. Army engineer combat service support.

time period.

Had the length of the network critical path been prohibitively lengthy, the army engineer could have used some of approximately twenty-five battalion-days of effort that were not allocated at the beginning of the forty-five day period. Note in Figure 11 that there is a buildup of unit allocation to the overall workload. This buildup is depicted in the unit-loading table to show that when new work is assigned the factors of both distance and time may preclude the immediate employment of all resources. Plans must provide time for unit relocations as well as for periodic rest and recuperation.

Figure 11 shows that by D+16 all nine engineer combat battalions will be fully committed through D+45. Any unforeseen delay will therefore result in an extension of the probable project completion date. This situation helps to point out the application of the network analysis system during project execution. Figure 11 shows the engineer which tasks are critical. It also shows, in conjunction with Figure 9, the interdependencies which exist between tasks. Therefore, if delays occur the network can be updated to reflect the new conditions. At this time, the army engineer can make a rapid appraisal of the situation and reallocate resources, as necessary, to cause the least delay in the project completion.

Another course of action may be available if rescheduling becomes necessary--additional resources might be available from sources within the theater. If so, the network model will be a useful tool in applying additional resources so as to keep the project on schedule.

During execution of this project the army engineer updates his network weekly to reflect trends and forecast problem areas before they arise.

Analysis of the Doctrine's Application

The previous example highlights some advantages as well as at least one limitation of the proposed doctrine, when it is used to plan and schedule engineer combat service support.

At first glance, the concept of network modeling seems to lose some of its value when the army engineer productively employs all his available units throughout the course of the project. If this happens he apparently has no additional resources available to allocate when unforeseen delays occur. Ordinarily, the network model can be useful to point out where slack time and corresponding idle resource exists. This particularly applies to planning research and development projects or contract construction, where variable resources will exist. When the Army engineer's available resources are rigidly constant he may not enjoy the benefit of flexible scheduling.

However, although the engineer habitually employs all available unit resources, this does not negate the possibility that he can acquire additional resources, if needed. For example, resources might be made available in the following manner:

(1) Indigenous labor.

(2) Engineer units from the Advance Section.

(3) Units which have been diverted from less critical activities by reducing the scopes of those activities, changing some job specifications, or by delaying their completion until adequate resource is available.

(4) Units which have been diverted from less critical activities, whose remaining units are required to complete the work with reduced forces.

(5) Units which are available for early reassignment, having completed their assigned activities ahead of schedule.

In light of this analysis, the networking technique appears to be of significant value to the army engineer for planning schedule revisions, as required. The time-scaled network accurately points out those activities which may be delayed to make resources available for critical tasks, without delaying the overall project completion date.

The sample planning problem also highlights two other uses for which the network analysis system was designed--as a tool to aid in initial planning, and in scheduling an operation.

It was shown above that the army engineer can use the planning doctrine to develop a methodology for accomplishing his work. A representative sample of planning restrictions were introduced to illustrate that operational planning may be quite complex. In this regard, the network analysis system is probably most valuable as a planning tool when it is used to plan for a multitude of interrelated requirements. On the other hand, the technique may not be worth the time and effort involved if relatively few activities are involved in the total planning task.

When his basic plan was completed the army engineer proceeded with little difficulty to schedule the operation. Each activity was scheduled in light of its relationships with the other work to be accomplished. The time-scaled network made the engineer cognizant of the interdependencies that exist between the activities. The probability of overlooking planning restrictions was significantly reduced.

Another identifiable advantage of the proposed doctrine is related to the army engineer's planning environment. The doctrine outlined earlier in this chapter provides the engineer with a logical sequence for accomplishing long-range planning. Wartime conditions can bring on mental fatigue, which will inhibit a planner's ability to clearly visualize and think through a proposed operation. The fast tempo of battle and related limited planning time also point up the need for a thorough discipline to guide the engineer and his staff in their planning.

Summing Up

The doctrine proposed in this chapter is based upon the field army engineer's specific requirement to engage in continuous long-range planning. The theory draws from the concept of network analysis as well as from the accepted sequence for Army planning. It forms a composite planning procedure. The concept that is proposed forces the army engineer to conduct very detailed planning. He must start with a broad approach to his planning requirement but proceed at a rapid pace to identify a host of facts about the proposed operation. The planning procedure establishes an orderly, though detailed, approach to operational planning.

The sequence described above utilizes a fictitious setting to demonstrate the mechanics of the proposed doctrine. The example shows that the army engineer can use this planning tool to visualize, plan, schedule and control the engineer brigade resources in a combat service support role. It stresses the use of two types of network model--the first not scaled to time, and the second oriented to a horizontal time-scale. A significant portion of the example points up the value of the networks in scheduling and revising a plan of action.

One general limitation came to light during the planning sequence. That is, the time-scaled network can easily become an inflexible planning tool if the army engineer has a fixed amount of unit resources with which to plan. However, this limitation is somewhat minimized through careful scrutiny of all sources of labor. It is concluded, therefore, that in many situations the field army engineer will have some measure of flexibility in planning and scheduling his combat service support operations. Consequently, the proposed doctrine can be a useful tool in planning, scheduling, and controlling a project.

Just as an operation's overlay graphically describes a proposed tactical concept of operations, so can a network diagram describe a method for accomplishing engineer work. Each in its own way reduces verbage and is an extremely valuable planning tool.

CHAPTER VI

TESTING THE DOCTRINE

Background

Choice of example.--The account of the Ninth U. S. Army engineer operations in the Rhine River crossing of World War II has been chosen to provide a vehicle to test the doctrine of network modeling. In his foreword to the Ninth Army Engineer report of the river-crossing operation, Brig. Gen. Richard U. Nicholas, Ninth Army Engineer from 1944 to 1945, noted that this operation "was the object of the most intensive planning and preparatory effort made by Ninth Army while operating in the European Theater".[1] The historical account of this action is chosen as a situation vehicle to test the doctrine proposed in Chapter V.

Intensive preparatory effort.--During a five month period the Ninth Army Engineer directed the bulk of his planning effort to preparations for crossing the Rhine River. Initially his own staff assisted him in drafting a broad outline of the plan. This action started in October 1944 when the Twelfth Army Group Commander established the tentative army crossing limits.

The specified Ninth Army mission included the following aspects:

(1) Effect a crossing between Orsoy and Rees (See Figure 12 in the next section of this chapter).

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[1]U. S., Forces, European Theater of Operations, Ninth Army, Engineer Section, "Ninth Army Engineer Operations in Rhine River Crossing," 30 June 1945.

(2) Construct three floating bridges, a heavy ferry, and a semi-permanent fixed bridge at Wesel.

(3) Clear the highway routes through Wesel.[2]

The army engineer analyzed his mission and formulated three implied tasks; these were:

(1) Support the crossings of two corps abreast, each with two infantry battalions in the initial assault.

(2) Construct three additional floating bridges.

(3) Construct seven antimine and antidebris booms.[3]

These tasks were based on a planned crossing date of 15 December 1944. He surmised that the magnitude of the Ninth Army crossing could be enlarged if this date was changed to a later date.

On 24 November he directed each of the three corps engineers to make initial plans for crossing the Rhine in their assigned sector.[4] At this time the army commander had not decided which two of the three corps would make the attack. Subsequently, the army engineer held several planning conferences with subordinate engineers. These meetings provided a free flow of ideas and led to the identification of many aspects that needed to be considered in planning.

In mid-December 1944 the German Army launched its now famous Battle of the Bulge. For the next six weeks most of the planning and training for the Rhine River crossing was suspended. A new date for the crossing was not initially set.

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[2]Ibid., p. 5.

[3]Ibid., p. 7.

[4]U. S., Forces, European Theater of Operations, Ninth Army, XVI Corps, Office of the Engineer, "Crossing the Rhine With the XVI Corps Engineers," 2 May 1945, p. 2.

During this period the fluid tactical situation still kept the army commander from deciding which corps would make the main effort in crossing the river. Finally, to preclude redundant planning, on 9 February 1945 the XVI Corps Commander was directed to prepare detailed plans for a corps size crossing.[5] He was told to plan a forced crossing of the Rhine in the vicinity of Rheinberg and establish an initial bridgehead.

On 25 February the army engineer issued formal planning guidance to the five engineer combat groups under army control. A letter of instructions assigned major tasks to each group and provided instructions pertaining to supply, training, and the design of certain bridges. Each group commander was directed to plan his part in the operation.[6]

On 4 March the XVI Corps was officially designated to make the army crossing. The target date was set as 31 March. This was later revised to 24 March, significantly shortening available preparation time.

The crossing.--At 0200, 24 March 1945, the XVI Corps attacked across the Rhine River, with the 30th and 79th Infantry Divisions abreast, to establish the Ninth Army bridgehead on the east bank of the river. Within four hours the assault elements of each division were across the river. Ferrying operations were started early that morning using primarily Navy lighterage.

Bridge construction started while the enemy still had observation of several crossing sites. However, the XVI Corps rapidly expanded the bridgehead and both the XIX Corps and XIII Corps passed through to continue the army attack to the northeast. By mid-April Ninth Army engineers had

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[5] Ibid.

[6] U. S. Forces, Ninth Army, Engineer Section, op. cit., Inclosure 4.

constructed a total of nine floating bridges and one fixed bridge across the Rhine River.[7]

A total of 31,120 non-divisional engineer troops took part in the Ninth Army Rhine River crossing operation.[8]

Testing the Doctrine

This section shows a test of the doctrine proposed in Chapter V. It determines to what extent the network analysis system could have been used by the Ninth Army Engineer to plan the Rhine River crossing. The following pages show a reconstruction of engineer activities as printed in the World War II reports. The historical facts are not changed; the text accurately reconstructs the events of March and April 1945. Unfortunately, no known record was found of how the Ninth Army Engineer conducted his planning. Therefore, the following sequence of planning is the thesis author's interpretation of how the plan and schedule was produced. The past tense is used to portray this concept. An evaluation of the doctrine's acceptability is made at the end of the chapter.

Preliminary Phase of Planning.--In October 1944, prior to the receipt of a formal planning directive, the Ninth Army Engineer commenced his planning for the Rhine River crossing. Coordinating with the army G3, he was told that the crossing would probably take place in December, with two corps abreast making the assault.

From a preliminary estimate of probable requirements the army engineer forecast that the following major tasks had to be completed in support of the operation:

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[7] *Ibid.*, p. 7.

[8] *Ibid.*, p. 51.

(1) Construction of two M2 treadway bridges.

(2) Construction of two 25-ton ponton bridges, reinforced.

(3) Construction of two Class 40 floating Bailey bridges, each with double landing bays to accommodate maximum variations in water levels of twenty-five feet.

(4) Construction of one semipermanent two-way Class 40, one-way Class 70 pile bridge.

(5) Construction of seven antimine and antidebris booms.[9]

In conjunction with the army G3, the engineer successfully tested several pieces of amphibious equipment on the Maas River. Other tests were conducted in November to develop methods for transporting bulky Navy lighterage overland.

These preliminary actions resulted in firm logistical efforts to procure the equipment that was needed for the operation. However, supply emphasis changed in December due to the tactical situation.

In early February 1945, having recovered from the effects of the German's December offense, the Ninth Army was placed under the operational control of the British Twenty-first Army Group. An exact sector was assigned for crossing the Rhine River.[10] At this point the army commander decided to make the crossing with one corps in the initial assault; see Figure 12.

Initial Phase of Planning.--Having received a definitive mission, the army engineer identified his prime objective as that of providing the boats, ferries and bridges that were necessary to insure the rapid and safe movement of the army across the Rhine River between Wesel and Orsoy, Germany.

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[9] *Ibid.*, p. 7.

[10] *Ibid.*, p. 5.

Coordinating with the army G3, the engineer determined that the three army corps would probably be abreast on the Rhine River at the time of the attack--the XVI Corps in the north, XIII Corps in the center, and XIX Corps in the south. However, as noted above, only one would make an assault crossing.

Studying the outline of the tactical plan, the army engineer established seven supporting objectives to sustain his prime objective in the operation. In addition, he outlined the work packages which, in his mind, related to the supporting objectives. His list of objectives and work packages are listed below:

(1) Activate and operate engineer bridge parks.

Work package: Bridge park operations.

(2) Complete engineer work required on the near shore.

Work package: Road rehabilitation and other near shore preparations.

(3) Conduct a deception operation south of the actual crossing site.

Work package: Deception operation in the XIII Corps zone.

(4) Provide close engineer support to the two assaulting divisions.

Work packages:

(a) Direct support to first division in assault.

(b) Direct support to a second division in assault.

(5) Provide engineer general support in the army area on a continuing basis.

Work package: Maintain roads west of the Rhine River.

(6) Assume responsibility for engineer work along the Rhine River,

from the XVI Corps Engineer, sometime about D+2.

Work packages:

(a) Consolidate bridge maintenance.

(b) Conduct salvage operations.

(7) Construct additional bridges to move the remainder of the army across the river.

Work packages:

(a) Construct additional float bridges, ferries and booms.

(b) Construct a fixed bridge.

Concurrently with the development of the detailed requirements, army engineer staff officers gathered intelligence data pertaining to the enemy, weather conditions, and the terrain along the river. Hydrographic data was also obtained.

Engineer supply officers followed up on requisitions for critical materiel.

In November 1944, a special stream crossing school was established at the Maas River to train personnel in the type operations that would be conducted along the Rhine. This school was operated until March 1945, except for a disruption during the Battle of the Bulge.[11]

The army engineer made continuous estimates to periodically update his concept of how the engineer operation was to be conducted. On 19 February an army letter of instructions was issued to XVI Corps which included directions for the corps to complete its plan for crossing the Rhine.[12] The letter included planning guidance pertaining to the availability of Class IV supplies, traffic planning, sites for construction of bridges, and time restrictions placed on the planning.

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[11] *Ibid.*, p. 12.

[12] Ibid., Inclosure 2.

The XIII Corps was instructed to plan a diversionary operation along the river to the south of the XVI Corps. A mock buildup of equipment was to be prepared. The intent was to make the Germans believe that the main army crossing would be in the zone of the XIII Corps.[13]

Preparation Phase of Planning.--While the corps developed their plans the Ninth Army Engineer continued to develop his detailed plans. He visualized the tasks that had to be accomplished in support of each work package. These tasks were then sequenced and listed in tabular form as shown in Table 8. In addition, Figure 12 shows a sketch of the proposed operations area.

Next, the army engineer drew a network diagram to represent his concept of the operation. The model is shown in Figure 13. It shows those tasks that were to be completed by non-divisional engineer units in support of the army during the river crossing operation. The model provided a tool for the engineer to study the interactions between the activities and the key milestones. It did not depict numerous minor tasks that would also be completed by subordinate units in support of the major tasks.

The model shown in Figure 13 has some distinctly different characteristics from those of the model in Figure 9, Chapter V. For example, a critical path of activity was not computed for Figure 13 simply because the length of the operation had been established by the tactical planners. Event 1 at D-10 was set as the earliest practicable date that bridge parks could be opened behind the river line. In addition, event 9, D-day, H-hour, was set as 0200, 24 March 1945. Also, event 28, D+2, 0600, was the earliest probable time that the corps would have advanced sufficiently

[13]Ibid., p. 55.

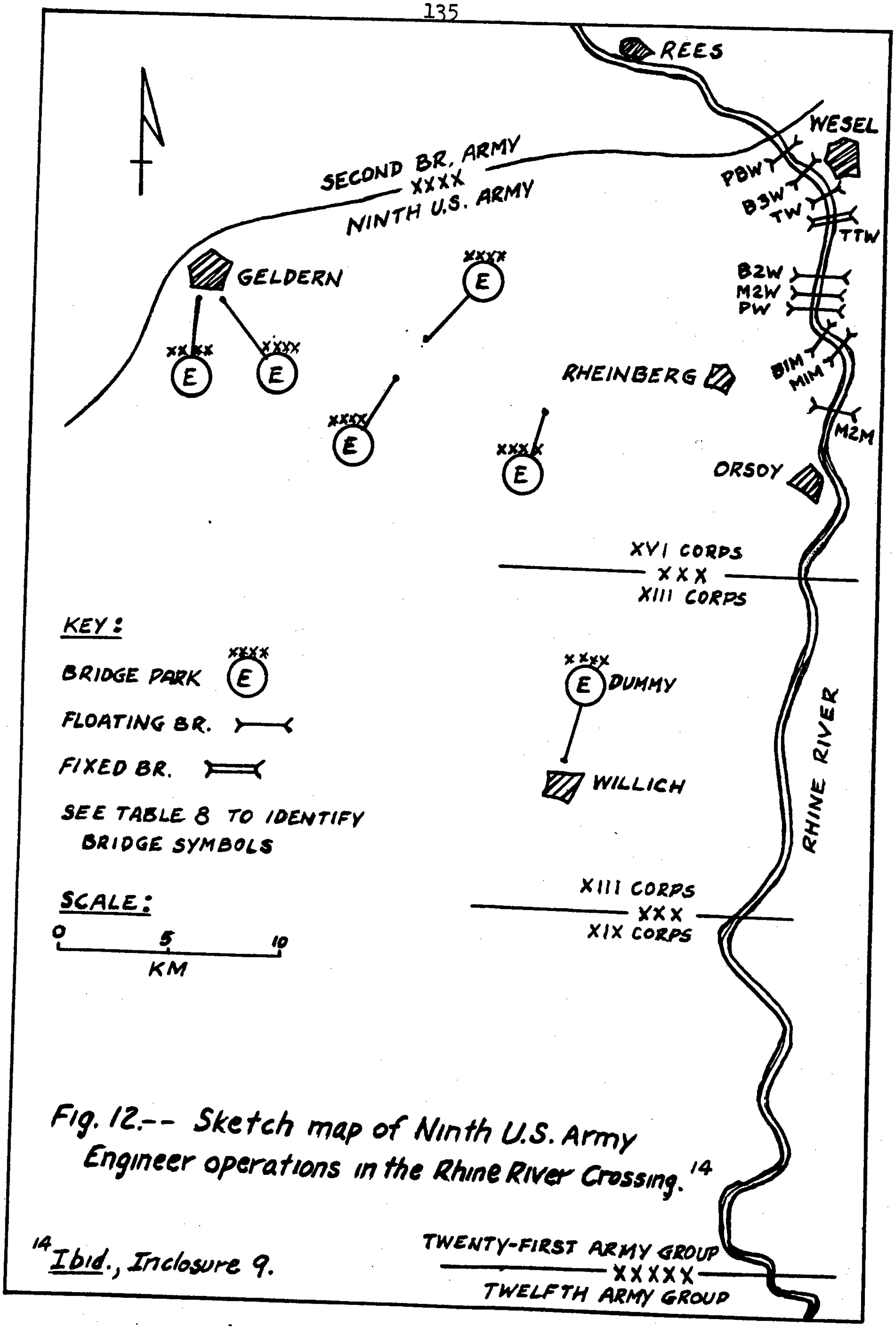


Fig. 12.-- Sketch map of Ninth U.S. Army Engineer operations in the Rhine River Crossing.[14]

[14] Ibid., Inclosure 9.

TABLE 8

TABULATION OF NETWORK DATA, RHINE RIVER CROSSING
BY NINTH U. S. ARMY

Work Package:

Task	Symbol	Description	Unit Resource [a]	Time Est. [b]	Earliest Starting Time	Latest Starting Time	Slack Time
(1)	Bridge Park Operations:						
1-2	AB1	Open Bridge Park 1	CB	9	D-10	D-10	0
1-3	AB2	Open Bridge Park 2	CB	9	D-10	D-10	0
1-4	AB3	Open Bridge Park 3	CB	9	D-10	D-10	0
1-5	AB4	Open Bridge Park 4	CB	9	D-10	D-10	0
1-6	AB5	Open Bridge Park 5	CB	9	D-10	D-10	0
(2)	Road Rehabilitation and Other Near Shore Preparations:						
1-9	RE	Rehab. Roads to Winter Dikes	CB, 2LE	9	D-10	D-10	0
7-9	E	Position Assault Equipment at Crossings	4CB	1	D-1	D-1	0
(3)	Deception Operation in XIII Corps Zone:						
1-8	K1	Construct Dummy Supply Dumps	4CB	6	D-10	D-10	0
8-9	K2	Conduct Near Shore Preparations	4CB	3	D-3	D-3	0

TABLE 8--Continued

Work Package:

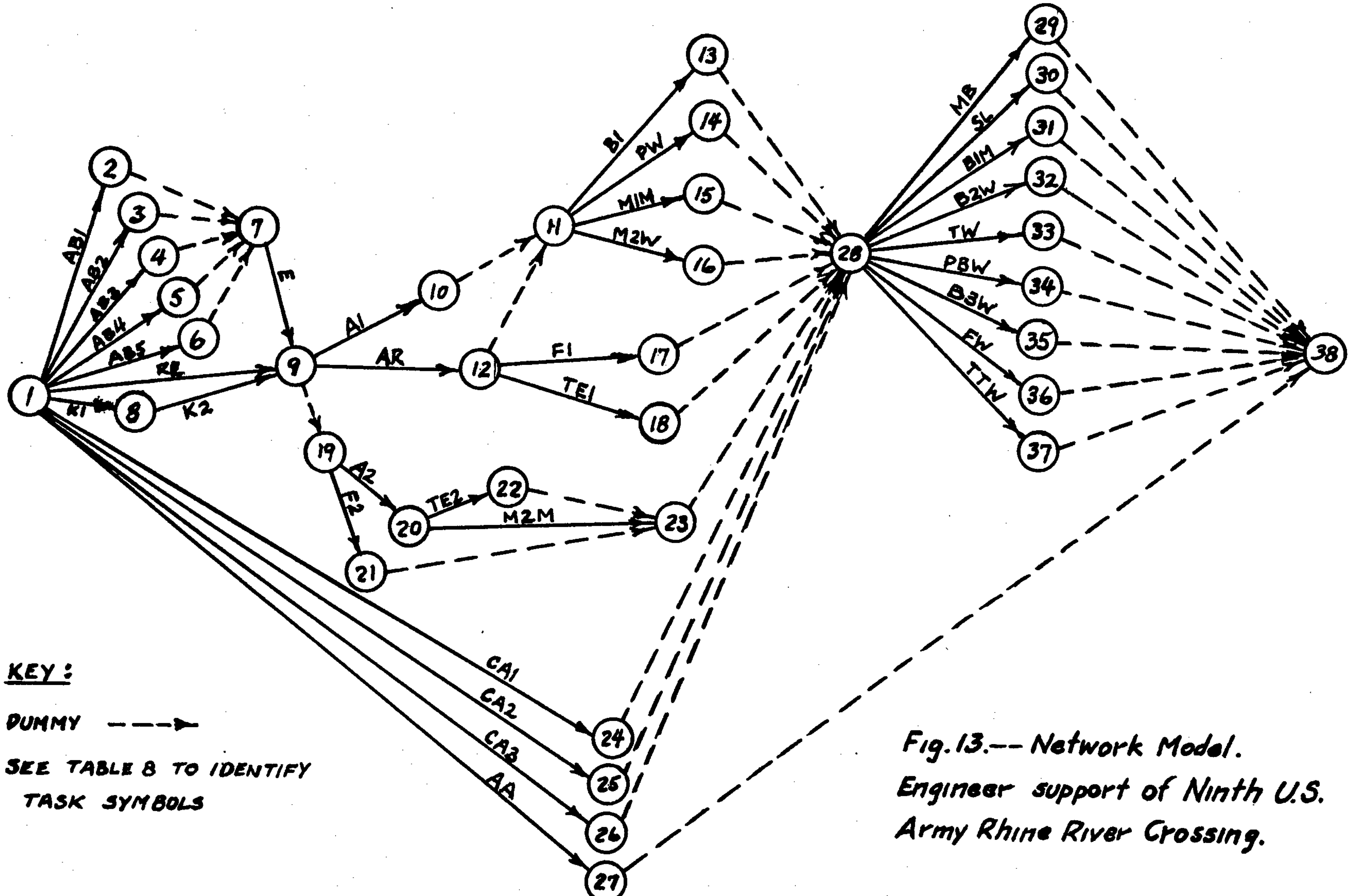
Task	Symbol	Description	Unit[a] Resource	Time[b] Est.	Earliest Starting Time	Latest Starting Time	Slack Time
(4)	Direct Support to First Division in Assault:						
9-10	A1	Operate Assault Boats	CB	4 hr	D-0200	D-0200	0
9-12	AR	Extend Approach Roads to River	CB	6 hr	D-0300	D-0300	0
12-17	F1	Construct and Operate Ferries	CB	2	D-0330	D-0330	0
12-18	TE1	Transport Bridge Equipment	DT	1	D	D	0
11-15	M1M	Construct M1 Treadway Br at Mehrum	CB	1	D	D	0
11-14	PW	Construct Ponton Bridge at Wallach	TBC, 2HPC, CB	1	D	D	0
11-16	M2W	Construct M2 Treadway Br at Wallach	CB, TBC	12 hr	D	D	0
11-13	B1	Construct booms	HPB	2	D	D	0
(5)	Direct Support to Second Division in Assault:						
19-20	A2	Operate Assault Boats	CB	4 hr	D-0300	D-0300	0
19-21	F2	Construct and Operate Ferries	CB	2	D-0400	D-0400	0
20-22	TE2	Transport Bridge Equipment	DT	1	D	D	0
20-23	M2M	Construct M2 Treadway Br at Milchplatz	CB, LE, TBC	1	D	D	0
(6)	Maintain Roads West of the Rhine River:						
1-24	CA1	Rehab. Roads in XVI Corps Area	CB	12	D-10	D-10	0
1-25	CA2	Rehab. Roads in XIII Corps Area	CB	12	D-10	D-10	0
1-26	CA3	Rehab. Roads in XIX Corps Area	CB	12	D-10	D-10	0
1-27	AA	Rehab. Roads in Army Service Area	5CB	40	D-10	D-10	0

TABLE 8--Continued

Task	Symbol	Description	Unit[a] Resource	Time[b] Est.	Earliest Starting Time	Latest Starting Time	Slack Time
Work Package:							
(7)	Consolidate Bridge Maintenance:						
28-29	MB	Maintain Bridges and Ferries in Sector	2CB	28	D+2	D+2	0
(8)	Conduct Salvage Operations:						
28-30	SL	Salvage Unserviceable Equipment on River	LPC	28	D+2	D+2	0
(9)	Construct Additional Float Bridges, Ferries and Boons:						
28-31	B1M	Construct BB Nr 1 at Mehrum	3CB, LE, DT	2	D+2	D+2	0
28-32	B2W	Construct BB Nr 2 at Wallach	3CB, DT, LE	3	D+2	D+2	0
28-33	TW	Construct M2 Treadway Br at Wesel	CB, TBC	12 hr	D+2	D+2	0
28-34	PBW	Construct Ponton Br and Booms at Wesel	HPB, CB, LE	18 hr	D+2	D+2	0
28-35	B3W	Construct BB Nr 3 at Wesel	CB, LPC	2	D+2	D+2	0
28-36	FW	Construct and Operate Class 70 Ferry, Wesel	CB(-)	23	D+2	D+2	0
(10)	Construct Fixed Bridge:						
28-37	TTW	Construct two-way Class 40, one-way Class 70 Fixed Br at Wesel	3CB	21	D+4	D+4	0

a KEY: CB - Engr Combat Bn
LE - Engr Lt. Equip. Co.
DT - Engr Dump Trk Co.
TBC - Engr Treadway Br. Co.
HPB - Engr Hvy Ponton Bn
LPC - Engr Lt. Ponton Co.

b Time estimates are in days, except as noted.



KEY:

DUMMY - - - ➤

SEE TABLE 8 TO IDENTIFY TASK SYMBOLS

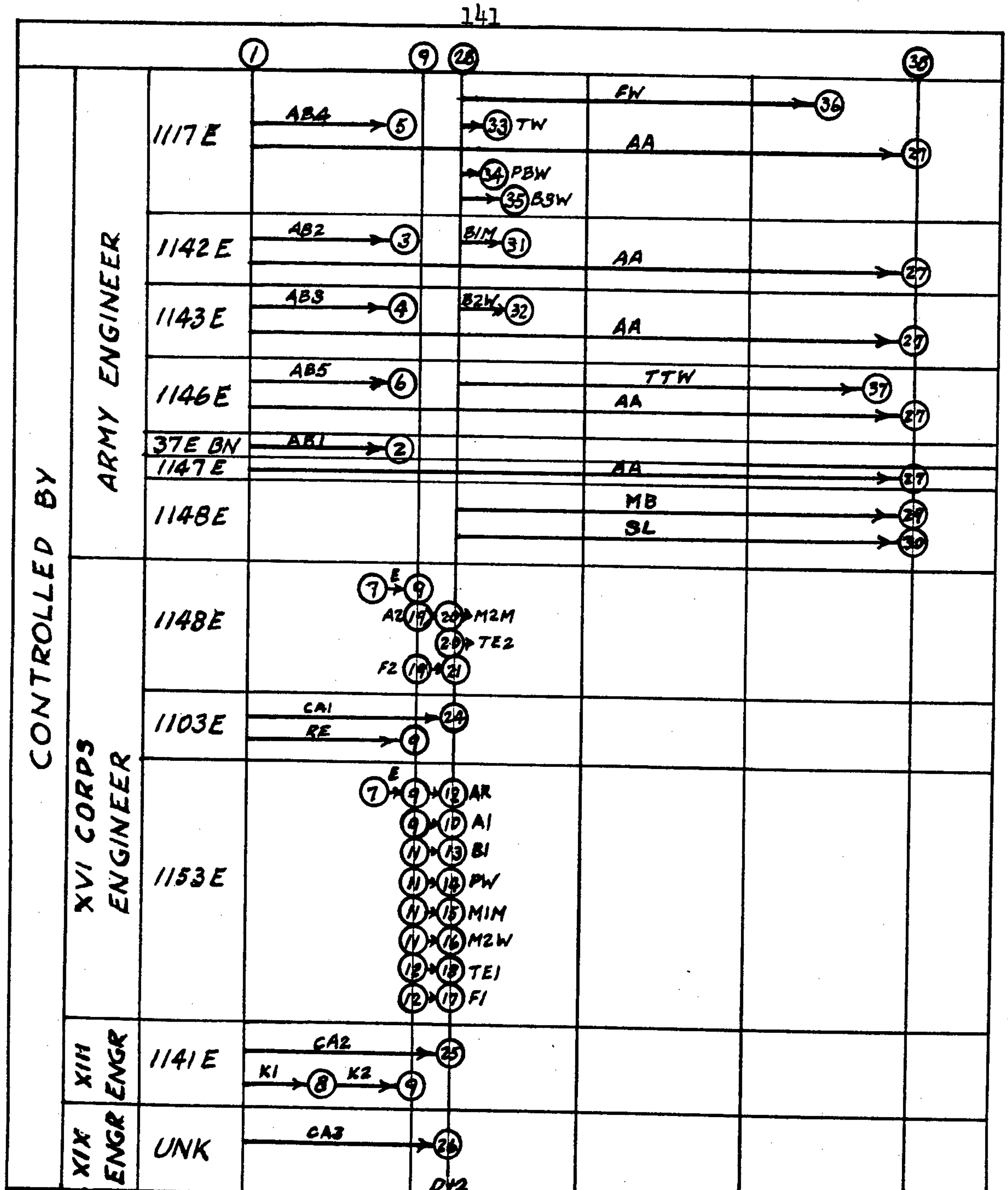
Fig. 13.—Network Model. Engineer support of Ninth U.S. Army Rhine River Crossing.

to the east so that the engineer work along the Rhine could be turned over to the army engineer. Finally, event 38, D+30, was the earliest probable time that the Advance Section Engineer could take over all engineer work along, and to the west of, the Rhine River. Therefore, events 1, 9, 28 and 38 were established as key milestones. Many of the activities were either started or completed when these key milestones occurred.

Figure 13 is also unique because with such rigid milestones there was no slack time on the paths of the network diagram. Some activities were not only started by the tactical sequence but were continued until their discontinuance was permitted by the course of the battle. A good example of this was the task of road rehabilitation.

Next in the planning sequence the army engineer allocated available engineer smaller units to the nine combat engineer group headquarters under army control. To do this the engineer redrew the network model by orienting it with both a horizontal time scale and a vertical unit scale. Activities were alloted to specific headquarters by considering the required times of execution, mutual locations, and the magnitudes of the tasks. The final time-scaled network is shown in Figure 14.

Using Figure 14, the engineer identified those unit resources that were required by each engineer group. By summing resource requirements vertically, and using the data shown in Table 8, the engineer determined how many of each type unit was needed for each group mission. He also determined the total number of each type unit required for the entire operation. The units not already in the theater were immediately requisitioned; these companies and battalions arrived in sufficient time to play important roles in the operation. Had insufficient time been available, the network model would have been modified to provide the most



UNIT RESOURCES REQUIRED

	D-10	D-DAY		D+2	D+10	D+20	D+30
CB	14	9	13	20	9	5	
LE	2	—	1	2	—	—	
DT	—	—	1	2	—	—	
TBC	—	—	2	1	—	—	
HPB	—	—	3	1	—	—	
LPC	—	—	—	3	1	1	

Fig. 14.-- Time-scaled network. Engineer support of Ninth U.S. Army Rhine River Crossing.

equitable concept of troop employment.

The final network model shows that the bulk of the units were required between D-10 and D+10. Therefore, as the corps advanced eastward the 1153d and 1103d Engineer Combat Groups were to remain attached to the corps with the army engineer retaining sufficient resources to accomplish the required engineer work.

On 25 February 1945 the army engineer had firmed up his plans sufficiently to issue a letter of instructions to the five engineer groups under his control.[15]

The army engineer encouraged his corps engineers and the group commanders to use the network analysis system in planning and scheduling their detailed projects. Networks were prepared by those subordinates and compared with the master network maintained by the army engineer. Required adjustments were made to the subordinate plans to make them compatible with the master plan.

Subsequently, the army engineer completed the last three phases of his planning--the approval, publication, and execution phases. All pre-H-hour requirements were completed as planned and the deliberate river-crossing was started on schedule.

As the operation progressed the engineer used the network model to compare scheduled event occurrences with actual times. When project completion times lagged the engineer transferred resources from elsewhere in the sector to augment work in critical areas. The network model helped the field army engineer to maintain a good perspective of the engineer situation throughout the operation.

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[15] U. S., Forces, Ninth Army, Engineer Section, op. cit., Inclosure 4.

Analysis of the Text

The preceding section generally described the magnitude of the army engineer's planning and operations during the Ninth Army Rhine River crossing of March 1945. The planning sequence proposed in Chapter V was used here to develop a detailed concept for conducting the engineer work. The tasks listed in the model were actually accomplished in the sequence described.

The tactical plan placed certain restraints upon the army engineer. Consequently, his plan was not so flexible as would be expected of a plan outlined by the networking technique. The timing for the engineer work was fairly well described by the key milestones. As a result, the length of the overall operation was fixed. There was no such entity as a critical time path, that might be shortened by applying additional resources. Likewise, there was no slack time available on any of the time paths to permit flexibility in scheduling task execution. This phenomenon will be characteristic of any network model which integrates combat support with a time-phased tactical plan.

Lacking scheduling flexibility, the army engineer was unable to use the network analysis system to either reduce the total length of the project or to make some savings in total resources. However, there were some distinct advantages accrued from using the planning tool.

First, the rigorous planning discipline established by the doctrine caused the army engineer to take a very detailed, logical, and accurate approach in his planning work. His planning progressed from a general analysis of requirements to a detailed investigation of the specific tasks that had to be completed. Even so, the army engineer did not become too engrossed in the minutiae of planning. He left the preparation of detailed sub-networks to those engineers who would be responsible for executing the actual tasks.

The second advantage gained by using the networking technique was attained from the model itself. In drawing the model the engineer developed a good perspective of the overall plan of action. All the engineer requirements were displayed on one easily comprehended diagram. This sketch, supplemented by data in tabular form, was an outline for subsequent planning and scheduling. Tracing the outline plan from event 1 through the final event, the engineer satisfied himself that his plan was basically sound.

A third advantage in using the technique was attained from the development of a time-phased network. This diagram, with the tabular data, summarized the requirements for unit resources and was the basis for requisitioning unit shortages.

A fourth advantage was gained in using the network model format. It was a useful work sheet for grouping the major tasks by both time and geographical location. Therefore, group task organizations were most advantageously tailored to meet the projected requirements.

As a fifth advantage, the network model indicated when, what, and where resources would probably become available for reassignment during the operation. The army engineer could forecast his requirements for units on the river line after the corps rear boundary was advanced to the east of the river.

Lastly, the network analysis system offered the army engineer a tool to stimulate coordinated planning action. His master network was available for subordinates to use as a basis for their own planning. As time progressed newly arrived personnel, liaison officers, and visitors were briefed by using the network model.

Modification of the Doctrine

Chapter VI has developed and analyzed the use of the network analysis system in planning engineer support for a major tactical operation. The example highlighted the fact that in engineer combat support operations the length of the required support is closely tied to the time-phased tactical plan. Therefore, a network diagram which represents such a plan will probably not have a critical time path. In addition, little or no flexibility may exist for scheduling the major engineer tasks. Instead, the engineer schedule will be synchronized with the maneuver units being supported.

Opposed to this application of network modeling is the use of the system which was described in Chapter V. In that chapter the technique was applied in a more conventional manner, where the tactical situation did not directly affect the length of the engineer operation. Hence, two general conditions have been identified which describe unique applications of the networking system--engineer combat support of time phased tactical operations, and engineer combat service support in the field army area.

The doctrine proposed in Chapter V must be modified slightly to accommodate this two-fold use of the technique. Under the paragraph titled, Preparation Phase of Planning, the following statement must be added to the instructions for computing a critical network path:

> "When the planned engineer tasks must be synchronized with a tactical operation the duration of the engineer effort will probably be set by the battle plan. Unavoidable time gaps will occur on many of the time-paths in the network. It will be impossible to calculate a time-length for each path. Therefore, it will be infeasible to identify a critical path. Under these conditions comply with guidance outlined below but ignore all references to a critical path or slack time."

Summing Up

This chapter has explored the feasibility of using the network analysis system to plan engineer effort required in support of a major field army operation. In retrospect, the test brought to light the fact that the tactical plan may often affect the timing established for the execution of the engineer support role. However, several advantages seemed to accrue when the field army engineer used the networking technique in planning. This tool of planning led him through a rather detailed analysis of the required support. He developed a good perspective of the overall operation. Scheduling was an easier job. Task organizations were realistically established by tailoring the composition of the engineer groups to accomplish specific missions. In general, he had a planning tool which guided his thought processes through the most difficult phase of planning--the development of workable procedures for executing the engineer mission. The planning doctrine assisted him not only in determining how to accomplish his work but also furnished a graphical representation of that plan.

The proposed doctrine, with a minor modification, had convincing application when used to plan the river-crossing operation. However, it was only one of the tools used by the engineer to complete his plans. It did not, nor does it propose to, stand alone as a complete answer to all planning requirements. Rather, the network analysis system helped the army engineer to draw in all the unique aspects of the total planning effort. His engineer estimates, terrain studies, troop lists, planning directives, bar-graph schedule, and operations order all contributed to the development of a complete plan. The model offered him an index and a focal point to guide and integrate all planning activity.

Since it is applicable in planning a river-crossing operation, the network analysis system should likewise be useful in planning other types of combat engineer support; the following are representative of other suitable uses:

(1) Engineer support in amphibious operations.

(2) Participation by engineers in the assault of a major fortified area.

(3) Engineer support in the resumption of the attack following a pause in offensive operations.

(4) Engineer assistance in preparing a major defensive position.

If he is to provide adequate and timely engineer combat support to the field army, the engineer must maintain a good perspective of the total engineer requirement. The network analysis system equips him with this capability.

CHAPTER VII

SUMMARY

The field army engineer is required to perform significant combat support and combat service support missions in the army service area. His personal job is generally one of planning, organizing, directing, and coordinating the overall engineer effort. The scope of his operations is characterized by centralized planning and decentralized execution. His combat support activities evolve around the close support of the corps both in offense and defense. One of his biggest missions is to support major river-crossing operations. The army engineer's combat service support tasks include road construction, fixed bridge construction, construction of air-landing facilities and, when necessary, port rehabilitation and railroad construction.

A general sequence for planning is described in Army literature to guide the engineer in his planning. For the most part the doctrine offers a comprehensive procedure for conducting detailed planning. However, there appears to be a theoretical gap in the planning sequence. Only scant guidance is offered to assist the engineer in determining how to accomplish his work.

In the past eight years the military and civilian industry have developed a new approach to planning called the network analysis system. Army doctrine states in Field Manual 5-162,[1] that the network analysis

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[1]U. S., Department of the Army, Engineer Construction and Construction-Support Units, FM 5-162 (Washington: U. S. Government Printing Office, August 1962), p. 13-8.

system is an acceptable approach to analyzing, planning, and scheduling construction projects. This paper has endeavored to expand this theory from a simple principle into a doctrine for the application of the network analysis system in operational planning by the field army engineer.

The proposed doctrine applies the network technique to expand that part of planning which deals with the task of visualizing how a project will be completed. The system provides a means for developing a mission statement into a methodology and outline schedule of the proposed operation.

The doctrine forces the army engineer to conduct detailed planning in order to prepare a graphical representation of the proposed work sequence. The model is a result of a logical and consistent approach to planning. On one planning document, it gives the engineer a thorough perspective of the overall plan.

This paper has developed two of the three significant aspects of the network analysis system. The first was just mentioned--the development of a model of the proposed plan of work. The second aspect is the evaluation and adjustment of the model to provide reasonable assurance that, if the plan is followed, the prime objective will be achieved. The third aspect, which pertains to the use of the model to control project execution, was only briefly discussed. This aspect was not discussed at length because the functions of project direction and control were beyond the scope of this paper.

Cost analysis and cost control was discussed at length in Chapter I. However, the doctrine does not incorporate the aspects of cost for good reasons. In the theater of operations combat engineers are not concerned with resource costs in terms of money. Rather, they strive for resource economy in terms of units, equipment, and materials. Economy is stressed in most engineer activities, being secondary in importance only to providing a degree of assurance that the mission will be accomplished.

As mentioned above, the army engineer is concerned with both combat and combat service type support. Consequently, this paper has distinguished one from the other, and proposes slightly different approaches to network analysis in each case. In Chapter V a sample planning problem described how the army engineer could improve his technique for planning combat service support by using the proposed doctrine. In contrast with this construction-type support behind the battle area, Chapter VI assessed the facility of the doctrine to improve long-range planning for a combat support operation. In this latter type of planning the army engineer is not so much interested in saving overall time as insuring that adequate and timely resources are provided to accomplish each engineer task.

The proposed doctrine expands but does not displace current Army planning doctrine. It aims to bridge the gap which seems to exist in Army planning between the development of an approved course of action and the creation of a scheduled plan of action.

No comparison has been drawn between the proposed doctrine and methods which have been in use in the field. Certainly, most engineers use some procedure, perhaps a self-developed technique, to sequence and schedule work. However, no known doctrine has universally been accepted. In light of this fact, this paper proposes the establishment of a standard doctrine.

The network analysis system is a logical way to accomplish the task of transposing a concept of operations into a detailed and scheduled plan for executing an assigned engineer mission. It can be used to assimilate a large number of interrelated facts and requirements to produce an orderly procedure for executing a mission. It graphically portrays conventional planning and emphasizes the processes of centralized control and decentralized execution. The graphical technique uses an easily understood set of conventions. The sketches can be a useful supplement to engineer plans much in the same manner that an operation overlay clarifies a tactical plan. A few simple sketches can significantly reduce the verbage required to describe a concept of operations.

The proposed doctrine will be of value to the army engineer and his planning staff whenever they are confronted with the task of planning a multitude of interrelated tasks, have a limitation on available resources, must meet an imposed project completion date, or must plan a combat support mission in synchronization with a time-phased tactical plan.

In conclusion, it is recommended that the proposed doctrine be tested in the field. The network analysis system has proven to be of significant value in planning construction projects in the United States. This paper has attempted to relate how this planning tool can likewise be a distinct asset to the field army engineer. Field testing should commence without delay and subsequently lead to the publication of revised Army planning doctrine.

APPENDIX A

MECHANICS OF NETWORK CONSTRUCTION

General.--The network model for a project should be prepared by a planning group that is familiar with the concept of the operation, as well as familiar with the techniques of networking. In addition, the contributions of operating personnel will aid planners considerably in the early stages of task identification and estimating.

Step 1: Define the prime objective.--The first step in network construction is to define the prime objective of the work to be accomplished. The prime objective identifies the mission toward which all planning is directed. For example, in military planning, the objective may be a restatement by the commander of the mission to be accomplished. This goal must be carefully selected and clearly stated.

Step 2: Identify supporting objectives.--The second step in network construction is to identify the supporting objectives that must be attained in order to reach the prime objective. The planner must have a good grasp of the concept of the proposed operation so that he is able to visualize and subdivide the major steps to be accomplished. Normally a supporting objective can be identified with each major step in the proposed work. In constructing a building, the supporting objectives might include the following: Completion of the earthwork, construction of the foundation, completion of the building shell, completion of the interior, and final inspection. The supporting objectives for a project may relate to equipment, services, facilities, decisions or completion of data preparation.[1] Together, these supporting objectives outline a general concept of how much work must be done to accomplish the prime objective. This planning technique provides for planning from the top down. It increases the probability that the overall program will be totally integrated and that each subdivision of work relates to the project as a whole.[2]

Step 3: Identify work packages.--At this point in the planning the major steps to be accomplished must be expanded to show the units of work required to attain each supporting objective. These units are called work packages because they normally relate to a work force, or supervisor in the proposed organization who will be responsible to accomplish the work. Work packages are associated with the skills and groupments of work required to complete each major step of the project. For example, in constructing a building the work packages associated with preparing the foundation might include the following items: formwork, concrete work, and inspection.

Step 4: Select the detailed tasks (activities) to be accomplished in each work package.--Planning has now progressed to the point where one or more work packages have been identified with each major step in the proposed project. Next, the planner must identify all the tasks that will be accomplished within each work package. In this step there is no substitute for careful and deliberate thought. The entire project must be visualized from start to finish. Experienced personnel should

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[1] U. S., Government, PERT Coordinating Group, PERT Guide for Management Use (Washington: U. S. Government Printing Office, June 1963), p. 13.

[2] Ibid.

be called upon to help the planner.

Step 5: Select the events to be accomplished.--The tasks (activities) are the time consuming elements in the network model to be constructed. Each activity must be limited by definable accomplishments in the project, which are called the project events. As noted in Chapter I, an event is a milestone in the project--a clearly identifiable point in time to mark the start or completion of a specific task. In simple networks, events can often be identified by number only. However, key events are often identified to mark the completion of each work package or major part of the project. This step is completed by the proper identification of an event to start and complete each activity.

Step 6: Sequence activities and events.--In visualizing the proposed work, the planner may be able to group certain activities which logically either start or are completed by a specific event. This technique is the start of the sequencing procedure. The objective of this step in the planning is to unfold the multitude of relationships and interdependencies that will exist between the activities. A good method to use in sequencing activities is to start with the end event and work backward to the starting event.

Three questions must be asked of each activity that is considered for use in the network:

(1) What task (activity) must immediately precede this one?

(2) What tasks (activities) may be accomplished at the same time?

(3) What tasks (activities) will immediately follow this one?[3]

To test each event, evaluate it by asking the following questions:

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[3]U. S. Sayer, J. E. Kelly, Jr. and M. R. Walker, "Critical Path Scheduling," Factory, July 1960, p. 76.

(1) Does the event define the beginning or end point of an activity or group of activities? If so what?

(2) Is the event, particularly key events, completely described?

(3) What activity or activities precede the event?

(4) What activity or activities follow the event?

The events that survive this close scrutiny will contribute materially in the network model.

The planner should: Vigorously review each activity and event in the manner noted above; develop an exact list of sequenced activities and their related events; number each event for ease of identification and likewise, letter each activity; group the activities by work package under each major step in the proposed work, and finally, check to confirm that each project supporting objective and the project prime objective are identified by a numbered key event. These key events can be used by the project management to check progress during actual execution.

Step 7: Lay out the network diagram.--Several types of graphical drawing aids will serve equally well in laying out the diagram.

Lay out the circles on the work board, properly numbered to represent each event. Place the first event on the far left and the final event on the far right. Apply the remaining events in between these two by ranking them vertically according to the work packages previously identified. At the same time rank the events horizontally according to the major project steps and activities' sequence previously developed. Do not put a date scale on the horizontal axis in order to avoid possible bias in subsequent time estimates. At the completion of this step the diagram is simply a groupment of numbered circles. If room permits, the network will be more easily understood if the meaning of the key events are written inside their respective circles.

Next, carefully connect the events with arrows to represent the network activities in the system. Utilize the previous lists that were developed to show event and activity sequences.

Rules of logic for network construction.--Certain rules of logic are prescribed for connecting events with activities. Figure 15 clarifies some of the most important rules as cited in the following list:

(1) Each activity must take place independently of all others.

(2) Each activity is constrained by two events, one at each end.

(3) An activity may not start until its preceding event has occurred.

(4) An event may not occur until all activities leading into the event have been completed.

(5) An event must be unique; it may not appear elsewhere in the network.

(6) No activity may go backwards in time; nor may there be any looping in the net.

(7) A dummy activity is used in the network for two purposes:

(a) To show dependency of one event upon another.

(b) To tie the end of one or more activities to the beginning of a single activity.

A dummy activity shows that its preceding event must occur before its succeeding event happens.[4] [5] [6]

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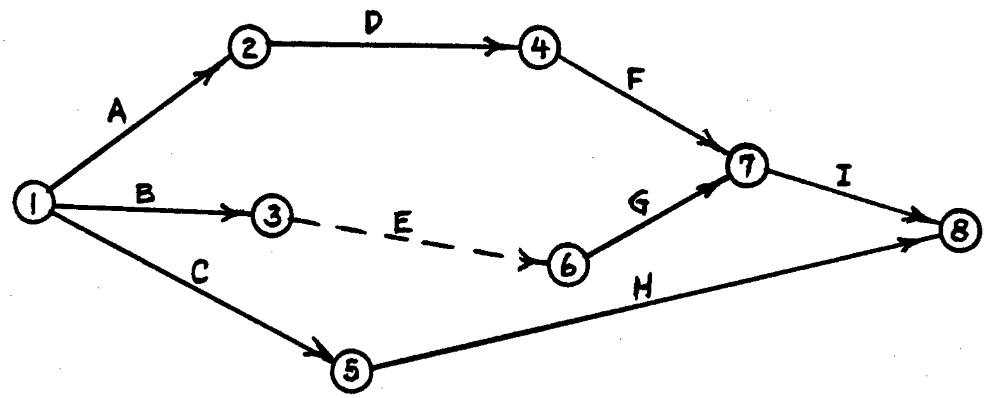
[4]Remington Rand Univac Corporation, Military Department, Fundamentals of Network Planning and Analysis (St. Paul: Remington Rand Univac, January 1962), p. 15.

[5]U. S., Government, PERT Coordinating Group, op. cit., p. 19.

[6]U. S., Department of the Air Force, Systems Command, "PERT-Time System Description Manual," Volume 1, September 1962, p. III-2.

SAMPLE NETWORK DIAGRAM



CLARIFICATION OF RULES

(1) Activity A is constrained by events 1 and 2.

(2) Activities A, B,and C occur concurrently but are independent of one another. The time required for each one has no bearing upon the others.

(3) Activity D cannot start until activity A is completed and event 2 has occurred.

(4) Event 7 cannot occur until both activities F and G are completed.

(5) Activity E is a dummy activity; it shows that activity G is dependent upon activity B, and that event 3 must occur before event 6 occurs.

Fig. 15.--Sample network diagram.

Summary.--The sequence of steps outlined above identifies the methodology for constructing a network model. The procedure forces the planner to proceed from the general to the specific and tends to keep his planning directed toward the accomplishment of the prime objective. The sequence of steps causes the planner to use a good deal of foresight and prudence as he lays out a procedure for accomplishing the prime objective.

His completed network model shows the interdependencies of the activities and events. The diagram does not indicate time requirements.

The next general step in the network analysis system is to apply resources to the diagram for accomplishing each activity. Subsequently, time estimates are prepared in accordance with some specific technique, such as PERT or CPM. Finally, if applicable to the analysis, the network can be oriented to a horizontal time scale to aid the planner in scheduling the project.

By no means will the first network diagram necessarily resemble the final network. A network diagram undergoes constant revision from its inception until the final objective is realized.

APPENDIX B

PERT TIME SYSTEM THEORY

Calculation of the Statistically Expected Time

Time estimates.--PERT uses three time estimates as the basic method for estimating the expected time to complete an activity--the optimistic, the most likely, and the pessimistic. These times are described as follows:

"(1) Optimistic time estimate (symbol a). The time in which the activity can be completed if everything goes exceptionally well. It is estimated that an activity would have no more than one chance in a hundred of being completed within this time.

"(2) Most likely time estimate (symbol m). The most realistic estimate of the time an activity might consume. This time would be expected to occur most often if the activity could be repeated numerous times under similar circumstances.

"(3) Pessimistic time estimate (symbol b). An estimate of the longest time an activity would require under the most adverse conditions, barring acts of God."[1]

PERT Time assumes that the "most likely time" represents the peak value of a probability distribution, best described by the Beta distribution.[2]

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[1]U. S., Department of the Air Force, Systems Command, "PERT-Time System Description Manual," Volume 1, September 1963, p. II-6.

[2]Robert W. Miller, "How to Plan and Control With PERT," Harvard Business Review, March-April 1962, p. 103.

This is not statistically correct because the mode of a set of measurements will rarely equal the mean of the set; however, PERT Time accepts this incongruity. The concept assumes that the distribution of activity times will have but one peak, and the peak is the most likely time for completion. Figure 16 represents this theory.

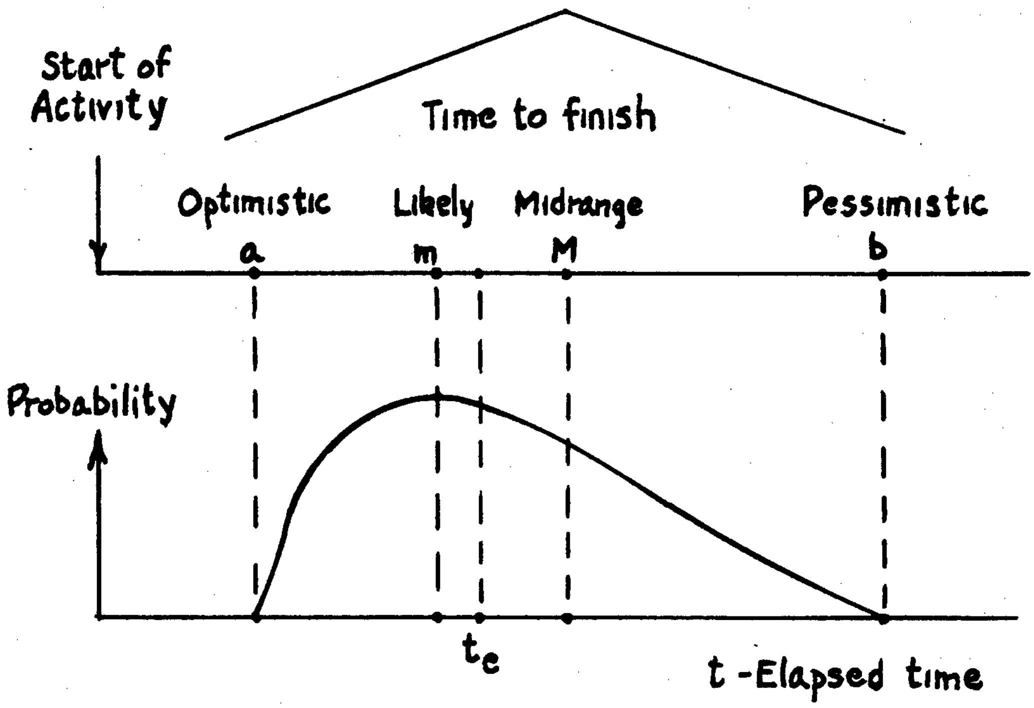

Fig. 16.--Beta distribution of probable times.[3]

In Figure 16:

(1) Then, $t_e = 1/3(2m + M)$ = The expected time.

$$= 1/3\left(2m + \frac{a+b}{2}\right)$$

$$= \frac{a + 4m + b}{6}$$

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[3] U. S., Army, The Engineer School, "Student Notes, Network Analysis System," Fort Belvoir, 1963, p. 22.

(2) Also, σ = The standard deviation of the expected time.

$$= \frac{b-a}{6}$$

(3) And, σ^2 = The variance of the expected time.[4]

$$= \left(\frac{b-a}{6}\right)^2$$

In the first equation te is shown as the weighted mean of m and M, with weights of 2 and 1 respectively. In the figure, te is located one-third of the way from point m toward point M; te divides the area under the Beta curve into two equal parts. The point te represents the 50 percent probability point of the distribution.

In the second equation σ provides a measure of the dispersion of the expected values of time.

In the third equation the symbol σ^2 is defined as the expected value of the square of the standard deviation of the random variable time, t. This expression is used below to calculate the probability of meeting a scheduled event time.

Probability of Meeting a Scheduled Event Time

Concept.--The Central Limit Theorem[5] [6] provides the basis for estimating the probability of meeting an expected project time (or any event time). The probability distribution of times for completing a network

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[4]Miller, loc. cit.

[5]Robert Hooke, Introduction to Scientific Inference (San Francisco: Holden-Day, Inc., 1963). The Central Limit Theorem states that with very weak restrictions, the sum of large numbers of random variables, whatever be the distribution, tends to be normally distributed. In the case at hand, the expected times of the activities along any path of a network are considered as a group of random variables. , p. 35.

[6]Harold Cramer, Mathematical Methods of Statistics (Princeton: Princeton University Press, 1951), p. 214.

event is approximated by the normal distribution. This approximation becomes more correct when a large number of activities have been completed prior to the scheduled event time, and in the same network path. Figure 17 shows this relationship.

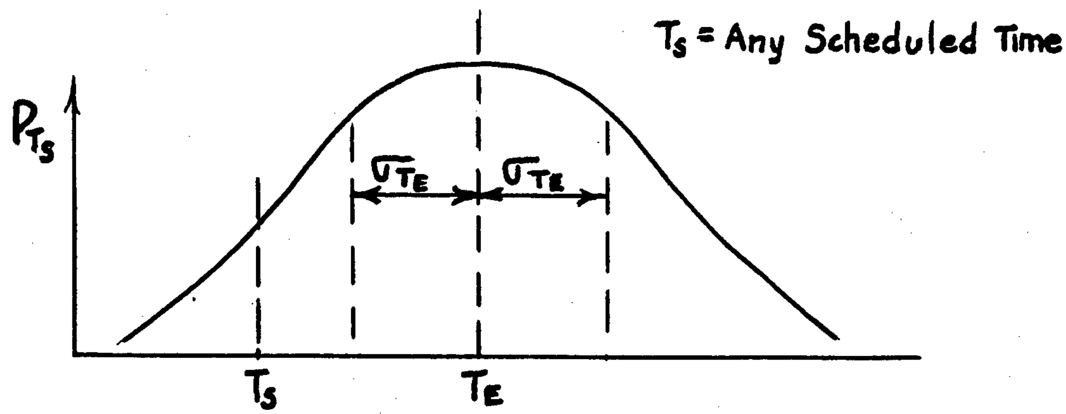

Fig. 17.--Normal distribution of expected event times.

In Figure 17:

(1) T_E = the sum of the expected times of the activities to the left and in the path of the event being studied. T_E is the expected event completion time. If the event being studied is the project completion time, then in this case, T_E equals the sum of the expected times along the critical path of the network.

(2) σT_E = the square root of the variance of the expected completion time.

(3) and,

σT_E^2 = the sum of the variances for each activity to the left and in the path of the event being studied.

= the variance of the expected completion time for the event.

Probability.--The probability of meeting the scheduled completion time, T_S, is defined as the ratio of the area under the curve, Figure 17, to the left of the time T_S, to the area under the entire curve.

An application of the use of this procedure to calculate the probability of meeting scheduled dates is presented in Chapter II.

APPENDIX C

THE ENGINEER ESTIMATE OF THE SITUATION

1. MISSION.

2. SITUATION AND COURSES OF ACTION.

   a. Obstacles to be overcome.

      (1) Time.

      (2) Material.

      (3) Equipment.

      (4) Personnel.

      (5) Weather.

      (6) Adverse terrain at or near the work site.

      (7) Enemy interference.

      (8) Other difficulties inherent in the situation.

   b. Means available.

      (1) Personnel.

      (2) Material.

      (3) Equipment.

      (4) Additional personnel - POWs, civilians, U. S. Forces.

   c. Own courses of action.

      (1) Prepare two or more feasible courses of action.

      (2) Consider assignment of work by area and/or task.

      (3) Tailor subordinate units for this specific mission.

3. ANALYSIS OF OPPOSING COURSES OF ACTION.

   a. Weigh each course of action against all obstacles to determine the strength and weaknesses inherent in each course of action.

b. Visualize both the risk and the degree of success anticipated from each course of action.

c. The advantages and disadvantages of each course of action should emerge from this analysis.

4. COMPARISON OF OWN COURSES OF ACTION.

a. Compare each course of action in terms of the meaningful advantages and disadvantages which emerged during the analysis in paragraph 3 above.

b. Select the most suitable course of action.

5. RECOMMENDATION.

Fully describe the course of action selected. Prepare a statement showing who, what, where, when, how, and why as appropriate.[1]

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[1]From the author's class notes, made at the U. S. Army Engineer School, subject: "Fundamentals of Command and Staff, The Engineer Estimate of the Situation," A. 113-7, 7 February 1961.

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